



**ELLIOTT BAY SEAWALL PROJECT SEASON 2 (2015)  
REVISED ACOUSTIC MONITORING REPORT  
(NWS-2011-778-WRD and NWR-2013-10650)**

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Prepared For:



City of Seattle Department of Transportation

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## 1.0 EXECUTIVE SUMMARY

This technical report presents the results of airborne and underwater sound level measurements conducted between October 30 and November 8, 2014 during installation of the first 5 unobstructed steel sheet piles with vibratory and impact hammers. This monitoring was conducted during Season 2 (2014/2015 in-water work window) of the Elliott Bay Seawall Project ("Project").

Vibratory sheet pile installation generated average underwater 10-second root mean square (RMS) sound levels ranging between 155 and 168 decibels (dB) re: 1 micropascal ( $\mu\text{Pa}$ ) and peak values between 173 and 186 dB re: 1  $\mu\text{Pa}$ . Measured underwater sound levels produced by vibratory pile driving are summarized in Table 1.1 below.

**Table 1.1** Measured Underwater Sound Levels from Vibratory Pile Driving, dB re: 1  $\mu\text{Pa}$

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-1	7 Hz-20 kHz	171	190	5	<b>181</b>	155	169	4	<b>163</b>	148	169	4	<b>164</b>
	75 Hz-20 kHz	171	190	4	<b>181</b>	155	169	4	<b>163</b>	147	169	4	<b>164</b>
	150 Hz-20 kHz	170	190	4	<b>181</b>	155	168	4	<b>163</b>	147	169	4	<b>163</b>
	200 Hz-20 kHz	171	190	4	<b>181</b>	155	168	4	<b>163</b>	147	168	4	<b>163</b>
VIB-2	7 Hz-20 kHz	166	182	4	<b>174</b>	144	164	3	<b>156</b>	148	166	3	<b>157</b>
	75 Hz-20 kHz	166	182	4	<b>173</b>	144	164	4	<b>156</b>	146	165	3	<b>156</b>
	150 Hz-20 kHz	166	182	4	<b>173</b>	143	163	4	<b>156</b>	146	164	3	<b>156</b>
	200 Hz-20 kHz	166	182	4	<b>173</b>	143	163	4	<b>155</b>	146	164	3	<b>156</b>
VIB-3	7 Hz-20 kHz	177	185	2	<b>182</b>	159	168	2	<b>166</b>	153	168	2	<b>166</b>
	75 Hz-20 kHz	177	185	2	<b>182</b>	159	168	2	<b>165</b>	153	168	2	<b>166</b>
	150 Hz-20 kHz	176	185	2	<b>182</b>	159	168	2	<b>165</b>	150	168	3	<b>165</b>
	200 Hz-20 kHz	175	185	2	<b>182</b>	158	168	2	<b>165</b>	150	168	3	<b>165</b>
VIB-4	7 Hz-20 kHz	180	195	3	<b>186</b>	163	174	2	<b>168</b>	146	175	3	<b>168</b>
	75 Hz-20 kHz	180	194	3	<b>186</b>	163	174	2	<b>168</b>	146	175	3	<b>168</b>
	150 Hz-20 kHz	181	193	3	<b>186</b>	163	174	2	<b>168</b>	146	175	3	<b>168</b>
	200 Hz-20 kHz	180	193	3	<b>186</b>	163	174	2	<b>168</b>	146	175	3	<b>168</b>
VIB-5	7 Hz-20 kHz	166	190	3	<b>183</b>	142	171	3	<b>167</b>	149	172	3	<b>167</b>
	75 Hz-20 kHz	167	190	3	<b>183</b>	142	171	4	<b>167</b>	149	172	3	<b>167</b>
	150 Hz-20 kHz	167	190	3	<b>183</b>	142	171	3	<b>167</b>	149	172	3	<b>167</b>
	200 Hz-20 kHz	167	190	3	<b>183</b>	142	171	3	<b>167</b>	148	172	3	<b>167</b>

Note: Underwater sound levels measured 10 meters from the piles.  
Source: The Greenbusch Group, Inc.

Average airborne sound levels produced by vibratory sheet pile installation ranged between 108 and 111 dB re: 20  $\mu\text{Pa}$ . Measured airborne sound levels are summarized in Table 1.2.

**Table 1.2** Measured Airborne Sound Levels from Vibratory Pile Driving, dB re: 20  $\mu$ Pa

Pile ID	Minimum	Maximum	Average
VIB-1	98	112	108
VIB-2	99	116	109
VIB-3	101	112	109
VIB-4	101	111	109
VIB-5	102	116	111

Note: Airborne sound levels measured 50 feet from the piles.

Source: The Greenbusch Group, Inc.

Impact driving of steel sheet piles produced broadband underwater 90% RMS (RMS<sub>90</sub>) sound levels between 180 and 185 dB re: 1  $\mu$ Pa and peak values between 192 and 198 dB re: 1  $\mu$ Pa. Table 1.3 below summarizes measured underwater sound levels generated by the impact hammer.

**Table 1.3** Measured Underwater Sound Levels from the Impact Hammer, dB re: 1  $\mu$ Pa

Pile ID	Frequency Range	Peak				RMS <sub>90</sub>				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-1	7 Hz-20 kHz	175	200	5	<b>192</b>	163	186	5	<b>180</b>	150	172	4	<b>166</b>	<b>190</b>
	75 Hz-20 kHz	175	200	5	<b>192</b>	162	186	5	<b>180</b>	150	172	4	<b>166</b>	<b>190</b>
	150 Hz-20 kHz	175	200	5	<b>192</b>	162	186	5	<b>180</b>	150	172	4	<b>166</b>	<b>190</b>
	200 Hz-20 kHz	175	200	5	<b>192</b>	162	186	5	<b>180</b>	150	172	5	<b>166</b>	<b>190</b>
IMP-2	7 Hz-20 kHz	189	204	1	<b>198</b>	176	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>198</b>
	75 Hz-20 kHz	189	203	1	<b>198</b>	175	189	1	<b>185</b>	164	173	1	<b>170</b>	<b>198</b>
	150 Hz-20 kHz	189	203	1	<b>198</b>	175	189	1	<b>185</b>	162	173	1	<b>169</b>	<b>198</b>
	200 Hz-20 kHz	189	203	1	<b>198</b>	173	189	1	<b>185</b>	162	173	1	<b>169</b>	<b>198</b>
IMP-3	7 Hz-20 kHz	189	204	2	<b>198</b>	174	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>202</b>
	75 Hz-20 kHz	189	204	2	<b>198</b>	174	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>202</b>
	150 Hz-20 kHz	189	204	2	<b>198</b>	174	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>202</b>
	200 Hz-20 kHz	189	204	2	<b>198</b>	174	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>202</b>
IMP-4	7 Hz-20 kHz	191	202	1	<b>197</b>	178	187	1	<b>184</b>	165	172	1	<b>169</b>	<b>199</b>
	75 Hz-20 kHz	191	202	1	<b>197</b>	179	187	1	<b>184</b>	164	172	1	<b>169</b>	<b>198</b>
	150 Hz-20 kHz	192	202	1	<b>197</b>	179	187	1	<b>184</b>	164	172	1	<b>169</b>	<b>198</b>
	200 Hz-20 kHz	192	202	1	<b>197</b>	179	187	1	<b>184</b>	164	172	1	<b>169</b>	<b>198</b>
IMP-5	7 Hz-20 kHz	190	204	1	<b>197</b>	177	188	1	<b>184</b>	163	173	1	<b>170</b>	<b>201</b>
	75 Hz-20 kHz	190	203	1	<b>197</b>	177	188	1	<b>184</b>	165	173	1	<b>170</b>	<b>201</b>
	150 Hz-20 kHz	191	202	1	<b>197</b>	177	188	1	<b>184</b>	163	173	1	<b>170</b>	<b>201</b>
	200 Hz-20 kHz	190	203	1	<b>197</b>	177	188	1	<b>184</b>	163	173	1	<b>170</b>	<b>201</b>

Note: Underwater sound levels measured 10 meters from the piles.

Source: The Greenbusch Group, Inc.

Average airborne sound levels produced by the impact hammer ranged between 109 and 116 dB re: 20  $\mu$ Pa. Measured airborne sound levels are summarized in Table 1.4.



**Table 1.4** Measured Airborne Sound Levels from the Impact Hammer, dB re: 20  $\mu$ Pa

Pile ID	Minimum	Maximum	Average
IMP-1	101	118	109
IMP-2	113	119	116
IMP-3	112	122	116
IMP-4	111	119	114
IMP-5	112	118	115

Note: Airborne sound levels measured 50 feet from the piles.

Source: The Greenbusch Group, Inc.

Based on the highest recorded broadband RMS value from vibratory sheet pile installation, the distance required for underwater sound levels to reach the marine mammal detection (Level B) threshold of 120 dB re: 1  $\mu$ Pa was calculated to be 9.9 miles. The calculated distance required for the highest measured RMS<sub>90</sub> sound level generated by impact driving of steel sheet piles to reach the 160 dB re: 1  $\mu$ Pa marine mammal detection (Level B) threshold is 1,532 feet.

Two different background sound level measurements were performed to assess underwater sound levels in Elliott Bay in the absence of in-water construction activities. One set of measurements determined background sound levels near the pile driving activities (near shore) and the other set (far field) was conducted to verify the results of a previous study conducted by the Washington State Department of Transportation (WSDOT) in 2011. Average background sound levels are summarized in Table 1.5.

**Table 1.5** Average Underwater Background Sound Levels, dB re: 1  $\mu$ Pa

Functional Hearing Group	Frequency Range	WSDOT Background Sound Level	Far Field Background Sound Level	Near Shore Background Sound Level
Low-Frequency Cetaceans	7 Hz – 20 kHz	130	140	128
Mid-Frequency Cetaceans	150 Hz – 20 kHz	124	120	123
High-Frequency Cetaceans	200 Hz – 20 kHz	124	120	123
Pinnipeds	75 Hz – 20 kHz	127	123	123

Note: The median was used to report the average background sound levels

Source: The Greenbusch Group, WSDOT report titled "Compendium of Background Sound Levels for Ferry Terminals in Puget Sound" issued April, 2014

Utilizing the highest measured average underwater RMS sound level produced during vibratory steel sheet pile installation of 168 dB and the average background sound levels ranging between 125 dB and 130 dB collected by WSDOT in 2011, the distances required to reach background sound levels (Level B) are up to 5.4 miles. The calculated distance required for the highest measured average RMS<sub>90</sub> sound level of 185 dB produced by impact driving of steel sheet piles to reach background sound levels is up to 72.9 miles using the background sound data collected by WSDOT. However, these distances are reduced due to the proximity of adjacent land masses. The WSDOT background sound levels were used rather than the near shore data collected by Greenbusch in 2015 because the WSDOT data more accurately describes the environment where marine mammals are likely to be present.

## 2.0 INTRODUCTION

This technical report presents the results of airborne and underwater sound levels measured during vibratory and impact pile driving of steel sheet piles associated with Season 2 (2014/2015 in-water work window) of the Project.

Consultation with the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Fish and Wildlife Service (USFWS) under the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (ESA) requires sound level monitoring for the first five unobstructed piles of each type and installation method. This acoustic monitoring technical report fulfills the requirements of the project's Biological Opinion, issued by NOAA and USFWS, and MMPA Letter of Authorization (LOA), issued by NOAA.

The Project construction area is located on Alaskan Way between Washington Street and Virginia Street in Seattle, Washington. Airborne and underwater sound level measurements were conducted between October 30 and November 8, 2014 during the installation of unobstructed steel sheet piles between Pier 55 and Pier 56 in Seattle, Washington. This area is located in Box 6 between Seneca Street and Madison Street (see Figure 2.1).

Marine mammal monitoring began on October 16, 2014. Acoustic monitoring did not coincide with the beginning of marine mammal monitoring because there were fixed obstructions between the piles installed prior to October 30 and potential monitoring locations. During Season 2, sound levels were measured from five unobstructed sheet piles installed with a vibratory hammer and five unobstructed sheet piles installed with an impact hammer as required by the Project's LOA and Biological Opinion. Pile installation with an impact hammer only occurred when the vibratory hammer was unable to drive the pile to the required depth. No concrete or other types of piles were installed in Season 2.

**Figure 2.1** Project Location and Construction Boxes



Source: The Greenbusch Group, Google Earth Pro, Mortenson/Manson

### 3.0 NOMENCLATURE

The auditory response to sound is a complex process that occurs over a wide range of frequencies and intensities. Decibel levels, or “dB,” are a form of shorthand that compresses this broad range of levels with a convenient, logarithmic scale.

Decibels are defined as the squared ratio of the sound pressure level (SPL) with a reference sound pressure. The reference pressure for airborne sound is 20 micropascals ( $\mu\text{Pa}$ ) and for underwater sound the reference pressure is 1  $\mu\text{Pa}$ . The use of 20  $\mu\text{Pa}$  in air is convenient because 1 dB re: 20  $\mu\text{Pa}$  correlates to the human threshold for hearing. It is important to note that because of these different reference pressures, airborne and underwater sound levels cannot be directly compared.

The following descriptors are referenced in this Report:

- **Background Sound Level**

The background sound level is the sound pressure level that describes the sound environment at a specified location during a specified time period and is also referred to as “ambient sound levels”. The measured sound levels include contributions from all sound sources, both local and distance, excluding specific sound sources of interest or under investigation.

- **Peak**

The peak sound pressure level is the instantaneous absolute maximum pressure observed during a measured event. Peak pressure can be presented as a pressure or dB referenced to a standard pressure (20  $\mu\text{Pa}$  for airborne and 1  $\mu\text{Pa}$  for underwater). Peak sound pressure is commonly used during hydroacoustic monitoring to assess the potential injuries to fish.

- **Root Mean Square (RMS)**

The RMS level is the square root of the average squared-pressure over a given time period. For vibratory pile driving RMS levels are calculated over 10 second periods. In hydroacoustics, the RMS level has been used by the National Marine Fisheries Service (NMFS) in criteria for assessing impacts to marine mammals.

- **90% Root Mean Square (RMS<sub>90</sub>)**

The RMS<sub>90</sub> level is used for the analysis of impact pile driving and is the RMS level containing 90 percent of the energy in a pile strike. The RMS<sub>90</sub> energy is established between the 5% and 95% of the pile energy and is calculated for each pile strike.

- **Sound Exposure Level (SEL)**

The SEL is the squared sound pressure integrated or summed over time referenced to a standard pressure squared (20  $\mu\text{Pa}$  for airborne and 1  $\mu\text{Pa}$  for underwater) normalized to one second and converted to decibels.

- **Cumulative Sound Exposure Level (cSEL)**

The cSEL is the SEL accumulated over time. In this report cSEL is calculated by adding the SEL corresponding to the absolute maximum peak pile strike to ten times the log of the number of pile strikes.

#### 4.0 REGULATORY CRITERIA

Anticipated airborne and underwater sound levels from the Project's LOA and Biological Opinion are presented in Table 4.1 below.

**Table 4.1** Predicted Unmitigated Underwater Sound Levels (ESA and MMPA Consultation)

Pile Type and Approximate Size	Method	Relative Water Depth of Piles	Average Sound Pressure Measured in dB re: 1 $\mu$ Pa	
			Peak	RMS
16.5 inch diameter precast concrete octagonal pile	Impact	~15 meters	188	176
Steel sheet pile pair, 48 inches long per pair	Vibratory (Installation and Removal)	~15 meters	182	165
Steel sheet pile pair, 48 inches long per pair	Impact (Installation Proofing)	~15 meters	205	190

Source: EBSP Updated Marine Mammal Monitoring and Mitigation Plan (April 2013), EBSP Biological Opinion (September 2013)

Because some of the piles driven in Season 1 exceeded the underwater sound levels indicated above, measured sound levels from Season 1 vibratory pile driving were used to estimate more realistic sound levels for subsequent EBSP pile installation. These predicted sound levels are included in a memorandum authored by The Greenbusch Group dated October 6, 2014 and attached to the Season 2 Letter of Authorization issued by NOAA. Table 4.2 provides these predicted underwater sound levels for vibratory pile installation.

**Table 4.2** Predicted Unmitigated Underwater Sound Levels (Based on Season 1 Sound Levels)

Predicted Season 2 Sound Levels	Average / Maximum Sound Levels at 10 meters, dB re: 1 $\mu$ Pa		
	Peak	RMS	SEL <sup>1</sup>
Vibratory Sheet Pile Installation	188 / 196	163 / 169	163 / 169

1. 1-second SEL

Source: Greenbusch Memorandum titled "EBSP Season 2 Hydroacoustic Monitoring Approach" dated October 6, 2014

Sound levels identified in Table 4.1 and Table 4.2 above are established 10 meters from the pile. RMS sound levels for piles driven with an impact hammer are RMS<sub>90</sub> sound levels.

The Project's LOA and Biological Opinion require reporting of underwater sound levels generated by the first five unobstructed piles of each pile type shown in Table 4.1 above. These reported sound levels must include the frequency spectrum, ranges and means for the peak and RMS sound pressure levels for each marine mammal functional hearing group, as well as the estimated distance required for the RMS values to reach the marine mammal thresholds and background sound levels. During impact pile driving, the pile strike resulting in the absolute highest peak sound pressure level must be used to calculate the cSEL of the pile drive.

As requested by NOAA during a conference call on September 22, 2014, sound levels measured during ramp-up activities are reported separately from sound levels measured during pile driving under full power. In addition, NOAA requested sound level data to include the range of SEL values. Consultation with NOAA and USFWS under the MMPA and ESA requires collection of underwater background sound levels. As a result of the September 22, 2014 coordination among NOAA, USFWS and SDOT, the parties agreed that background sound level measurements would

be collected between 500 and 1,000 meters from the construction area to verify that sound levels reported by WSDOT in 2011 had not changed and that additional data would be collected approximately 10 meters from the monitored piles.

## 5.0 PILE AND PILE DRIVING EQUIPMENT INFORMATION

During Season 2, all steel sheet pile installation was initiated with a vibratory hammer. In some places, the vibratory hammer was unable to drive the piles to the required depth and it was necessary to drive the remainder of the pile with an impact hammer. The steel sheet piles consist of two 72 foot long and 2 foot wide A242 steel sheet piles welded together. In all cases, the substrate the sheet piles were driven into was hard, rocky and covered with silt and marine debris.

Sheet piles installed using a vibratory hammer were driven with an APE 250VM Vibratory Driver/Extractor operating at a frequency of 1,750 VPM generating a driving force of 196 tons. The suspended weight with a clamp and 75 foot long hose is 17,500 pounds. A cut sheet of the vibratory hammer can be found in the Appendix of this Report. Table 5.1 presents a summary of the sheet piles driven with a vibratory hammer while sound level monitoring was occurring.

**Table 5.1** Summary of Sheet Piles Driven with a Vibratory Hammer, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Drive Time (minutes)
VIB-1	10/30/14	None	3	20	40	16
VIB-2	10/30/14	None	3	20	40	16
VIB-3	10/31/14	None	3	20	40	10
VIB-4	10/31/14	None	3	20	40	12
VIB-5	11/7/14	None	3	16	44	30

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Logs

Impact driving of the steel sheet piles was conducted using an APE Model 6-2 Hydraulic Impact Hammer with a rated energy rating of 24,000 foot-pounds. The ram weight was 12,000 pounds and the stroke achieved when operating at the energy rating was 24 inches. The hammer operated at between 45 and 75 blows per minute. Table 5.2 presents a summary of sheet piles driven by an impact hammer while sound monitoring was occurring.

**Table 5.2** Summary of Sheet Piles Driven with an Impact Hammer, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Number of Strikes <sup>1</sup>
IMP-1	11/7/14	None	3	20	40	87
IMP-2	11/8/14	None	3	20	40	471
IMP-3	11/8/14	None	3	20	40	989
IMP-4	11/8/14	None	3	18	42	658
IMP-5	11/8/14	None	3	16	44	896

1. Number of strikes reported on pile driving logs. This number differs from the number of pile strikes analyzed as only strikes made at full power were included in the analysis. The numbers of strikes analyzed are reported in later sections of this Report.

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Driving Logs

## 6.0 MEASUREMENT METHODOLOGY

### 6.1 Equipment

Equipment used to collect airborne sound data during pile driving are identified in Table 6.1.

**Table 6.1** Airborne Sound Measurement Equipment

Make and Model	Description	Serial Number
Brüel & Kjaer Type 2250	Sound Level Analyzer	3006756
Brüel & Kjaer ZC0032	Preamplifier	9437
Brüel & Kjaer 4189	Microphone	2550228
Brüel & Kjaer 4231	Acoustic Calibrator	2545696
Rion NL-52	Sound Level Analyzer	821097
Rion NH-21	Preamplifier	21138
Rion UC-59	Microphone	4064
Larson Davis CAL200	Acoustic Calibrator	9253
Rion NL-32	Sound Level Analyzer	00161681
Rion NH-21	Preamplifier	18454
Rion UC-53A	Microphone	309751
Larson Davis CAL200	Acoustic Calibrator	5463

Source: The Greenbusch Group, Inc.

Table 6.2 identifies equipment used to measure underwater sound levels during pile driving and both sets of background sound level measurements.

**Table 6.2** Underwater Sound Measurement Equipment

Make and Model	Quantity	Description	Serial Number
Brüel & Kjaer Type 2250	1	Sound Level Analyzer	3006756
Brüel & Kjaer Type 2270	1	Sound Level Analyzer	2679351
Reson TC-4013	3	Hydrophone	2513032
			1812260
			0712203
Brüel & Kjaer Type 2647-A	2	Charge Converter (1 mV/pC)	2582112
			2638259
PCB 422E02	1	Charge Converter (10 mV/pC)	36640
G.R.A.S. Type 42AC	1	Pistonphone	201835
Getac S400	1	Laptop Computer	RBB39S0072
National Instruments NI USB-4431	1	4 Channel DAQ	14F31A5
PCB Model 482A16	1	Signal Conditioner	2987

Source: The Greenbusch Group, Inc.



All measurement equipment was factory calibrated within 1 year of the measurement date. Field calibrations were performed each day prior to monitoring and verified at the end of each day. Calibration tones were also recorded from each hydrophone before every day of monitoring. Hydrophones were calibrated using the G.R.A.S. pistonphone.

On October 30 and October 31, 2014, airborne sound levels were measured with the Brüel & Kjaer Type 2250 sound level analyzer. During these dates, two Reson TC-4013 hydrophones were attached to the PCB Model 482A16 signal conditioner. The signal conditioner was attached to the National Instruments NI USB-4431 4-channel data acquisition system, which transferred the data into a laptop. The laptop recorded the time waveforms from each pile driving event for subsequent signal analysis. This equipment setup allowed for real-time approximations of peak sound levels while the measurements were being performed. Photos illustrating the airborne and underwater measurement equipment used on October 30 and October 31, 2014 are provided in Figure 6.1 and Figure 6.2.

**Figure 6.1** Airborne Measurement Equipment



Source: The Greenbusch Group, Inc.

**Figure 6.2** Hydroacoustic Equipment



Source: The Greenbusch Group, Inc.

Damage was sustained to the laptop computer and Reson TC-4013 (SN 2513032) after they were used on October 31, 2014. As a result, the Brüel & Kjaer Type 2250, Brüel & Kjaer Type 2270, Rion NL-52, and Rion NL-32 were used to measure underwater and airborne sound levels on November 7 and November 8, 2014.

On November 7 and November 8, 2014, broadband airborne sound levels were measured using the Rion NL-52. Airborne spectral data was gathered using the NL-32 sound level analyzer. During these dates two Reson TC-4013 hydrophones were attached to the Brüel & Kjaer Type 2647-A in-line charge converters. These charge converters were attached to the Brüel & Kjaer Type 2250 and Brüel & Kjaer Type 2270 sound level analyzers. The sound level analyzers



recorded WAV files of the pile driving activity for subsequent signal analysis. This equipment setup allowed for real time approximations of peak sound levels. Photos of the airborne and underwater sound measurement equipment used on November 7 and November 8, 2014 are provided in Figure 6.3 and Figure 6.4.

**Figure 6.3** Airborne Measurement Equipment



Source: The Greenbusch Group, Inc.

**Figure 6.4** Hydroacoustic Equipment



Source: The Greenbusch Group, Inc.

## 6.2 Measurement Locations

Airborne sound level measurements were made 50 feet (15 meters) from each pile being driven. The distance between the microphone and pile was determined using a laser distance measure. The microphone was located approximately 7 feet above the pier and a clear line-of-sight was maintained between the microphone and each pile driven.

Hydroacoustic monitoring was performed using two hydrophones located approximately 33 feet (10 meters) from the piles being driven. The exact distances between the piles and hydrophones ranged between 32 feet and 35 feet and are provided in Table 6.3. The distance between the hydrophones and piles were verified for all monitored piles using a laser distance measure. Hydrophone locations were selected based on site access and to achieve an unobstructed path between the hydrophones and piles.

One hydrophone was positioned 3.3 feet (1 meter) below the surface and the second hydrophone was positioned 3.3 feet (1 meter) above the sea floor. Water depth was measured at the hydrophone deployment locations, as well as each time the hydrophones were relocated. The depth of the upper hydrophone was maintained by suspending the hydrophone below a buoy. The lower hydrophone remained 3.3 feet (1 meter) above the sea floor by placing the hydrophone on a weighted line and attaching a float below the surface above the hydrophone. This float did

not provide enough buoyancy to lift the weight but provided enough force to suspend the hydrophone. This technique eliminated any slack in the line caused by tidal changes.

In addition to water depth measurements, tidal information was obtained from NOAA Station #9447130 and was used to track tidal changes during construction and to calculate the resulting distance between the two hydrophones. Table 6.3 presents the depth of the hydrophones, water depth at the measurement location, distance between the hydrophones and distance between the hydrophones and the pile.

**Table 6.3** Hydrophone Location Summary, Feet

Table 6-6 Hydrophone Location Summary, Feet					
Pile ID	Depth at Measurement Location <sup>1</sup>	Hydrophone	Hydrophone Depth	Distance between Hydrophones	Distance to Pile
Vibratory Installation					
VIB-1	35	Upper	3	28	34
		Lower	32		
VIB-2	32	Upper	3	26	33
		Lower	29		
VIB-3	39	Upper	3	32	33
		Lower	36		
VIB-4	40	Upper	3	33	33
		Lower	36		
VIB-5	28	Upper	3	22	34
		Lower	25		
Impact Installation					
IMP-1	32	Upper	3	25	32
		Lower	28		
IMP-2	33	Upper	3	27	33
		Lower	30		
IMP-3	32	Upper	3	26	34
		Lower	29		
IMP-4	31	Upper	3	25	35
		Lower	28		
IMP-5	32	Upper	3	25	33
		Lower	28		

1. Depth at start of pile drive  
Source: The Greenbusch Group, Inc. NOAA Station #9447130

Figures illustrating the airborne and underwater measurement locations for each pile are presented in Sections 9 and 10 of this Report.

## 7.0 BACKGROUND SOUND LEVEL MEASUREMENT METHODOLOGY

Measurements of background underwater sound levels were conducted at two locations in the absence of in-water construction activities to determine the distance required for the RMS sound levels produced by pile driving to attenuate to background sound levels.

One set of background sound level measurements was made approximately 1,200 meters to the west of the Box 6 (see Figure 7.1). These measurements satisfied the background sound measurement requirements of the ESA and MMPA consultation and verified that ambient sound levels have not significantly changed from those measured by WSDOT in 2011. At the request of NOAA, a second set of measurements was conducted near shore, approximately 10 meters from the pile driving location (Figure 7.11).

All background sound level measurements were made using a Reson TC-4013 hydrophone attached to a PCB 422E02 10 mV/pC in-line charge converter. This charge converter was attached to the Brüel & Kjaer Type 2270 sound level analyzer. The hydrophone depth was between mid-water column and 4 meters from the sea floor.

10-second RMS data collected during periods when pile driving activities are permitted (30 minutes after sunrise and 30 minutes before sunset) was used to calculate the cumulative density function (CDF) of each marine mammal functional hearing group in accordance with the NOAA Guidance Document: "Data Collection Methods to Characterize Underwater Background Sound Relevant to Marine Mammals in Coastal Nearshore Waters and Rivers of Washington and Oregon" dated January 31, 2012. The marine mammal functional hearing groups are presented in Table 7.1.

**Table 7.1** Marine Mammal Functional Hearing Groups

Functional Hearing Group	Low Frequency	High Frequency
Low-Frequency Cetaceans	7 Hz	20 kHz
Mid-Frequency Cetaceans	150 Hz	20 kHz
High-Frequency Cetaceans	200 Hz	20 kHz
Pinnipeds	75 Hz	20 kHz

Source: NOAA Guidance Document: "Data Collection Methods to Characterize Underwater Background Sound Relevant to Marine Mammals in Coastal Nearshore Waters and Rivers of Washington and Oregon" dated January 31, 2012

The overall broadband background sound levels for each hearing group described in Table 7.1 is reported as the 50<sup>th</sup> percentile of the CDFs.

### 7.1 Far Field Background Sound Levels

Short-term background sound level measurements were made approximately 1,200 meters to the west of Box 6 on January 3, January 7, and January 8, 2015 for approximately 1 hour during daytime hours. Measurements were conducted from a drifting boat. Data collection over three consecutive days was not possible due to adverse weather conditions. These measurements were used to verify that background sound levels measured by WSDOT during April 2011 had not changed significantly.

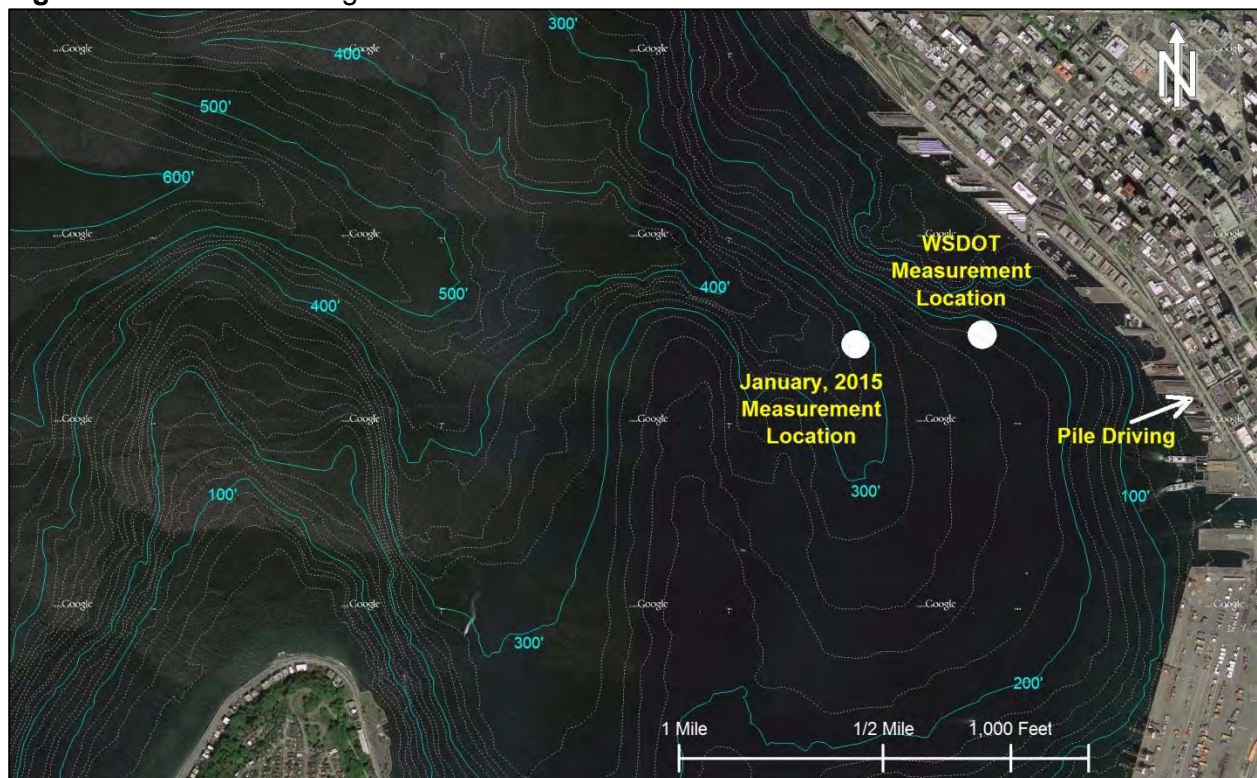
WSDOT collected background sound levels in Elliott Bay over three consecutive 24-hour periods between April 19 and April 22, 2011. These measurements are presented in a report titled "Compendium of Background Sound Levels for Ferry Terminals in Puget Sound" issued April 2014. By demonstrating that the short-term measurements conducted in January 2015 do not

vary significantly from the daytime levels reported by WSDOT, the long term data collected by WSDOT can be used to calculate the distance required for noise from pile driving to reach background sound levels.

Figure 7.1 below presents the location of the January 2015 measurements and the approximate WSDOT 2011 measurement location.



**Figure 7.1** Far Field Background Sound Level Measurement Locations



Source: The Greenbusch Group, Inc. Washington State Department of Transportation report "Compendium of Background Sound Levels for Ferry Terminals in Puget Sound" issued April, 2014

Equipment used to collect short term background sound data is shown in Figure 7.2.

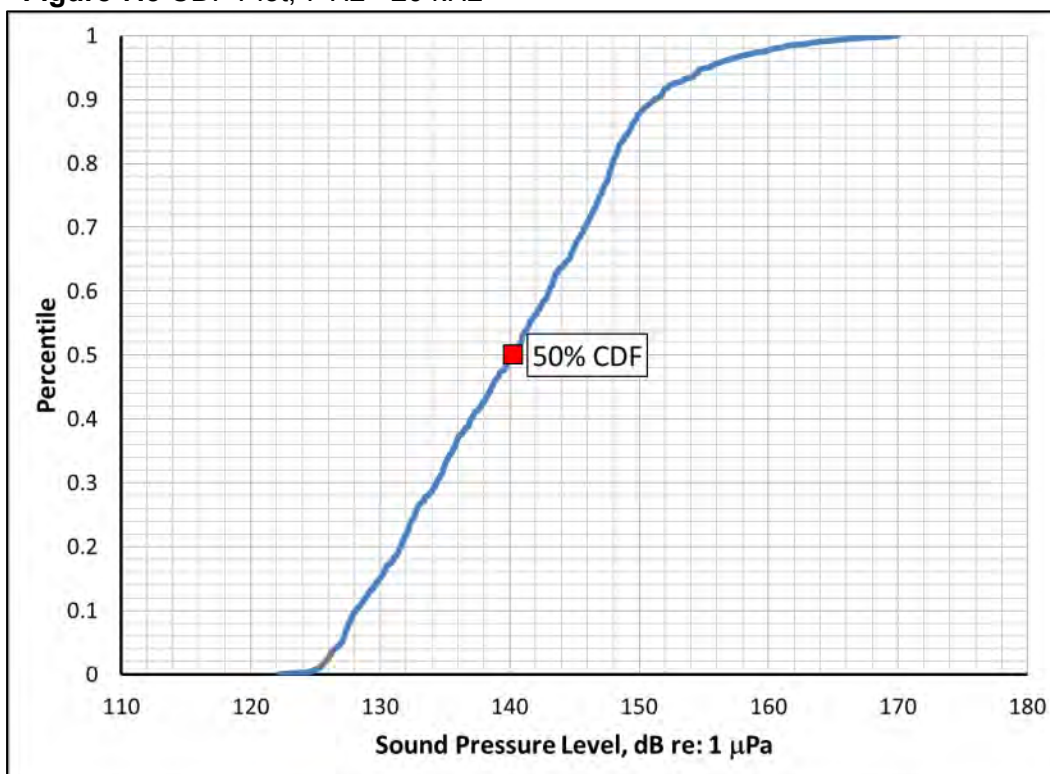
**Figure 7.2** Far Field Background Sound Measurement Equipment



Source: The Greenbusch Group, Inc.

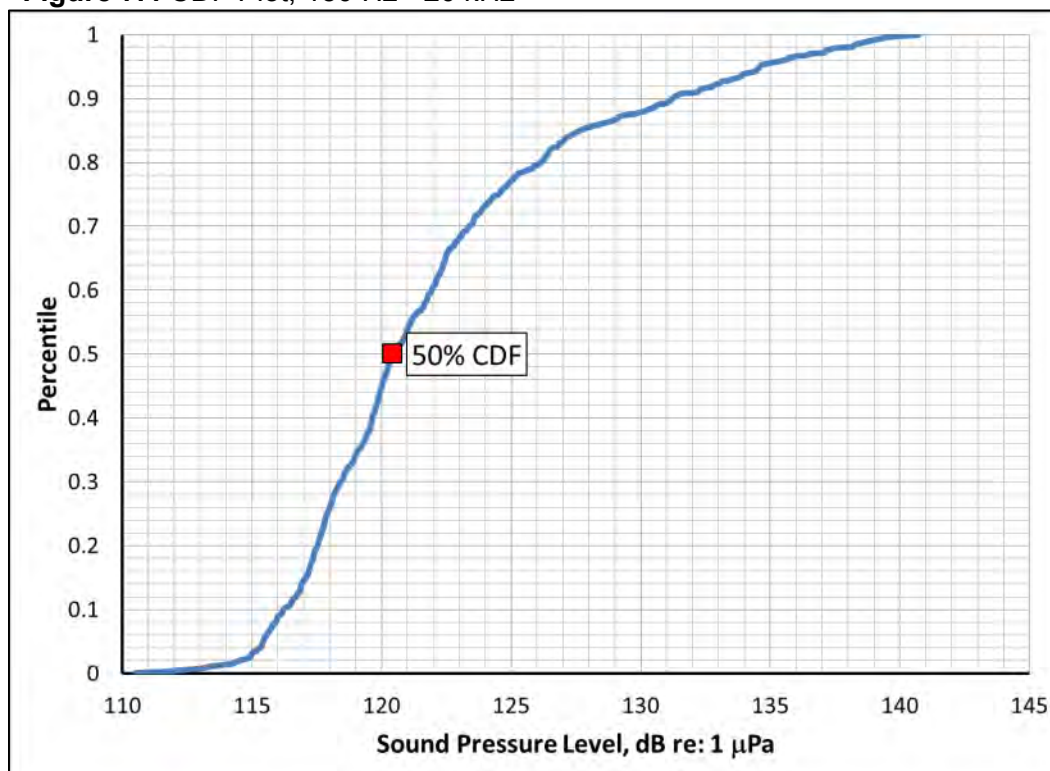
10-second RMS values were used from short term measurements conducted in January 2015 to generate CDF plots for each marine mammal functional hearing group. These CDF plots are presented in Figure 7.3 through Figure 7.6.

**Figure 7.3** CDF Plot, 7 Hz - 20 kHz



Source: The Greenbusch Group, Inc.

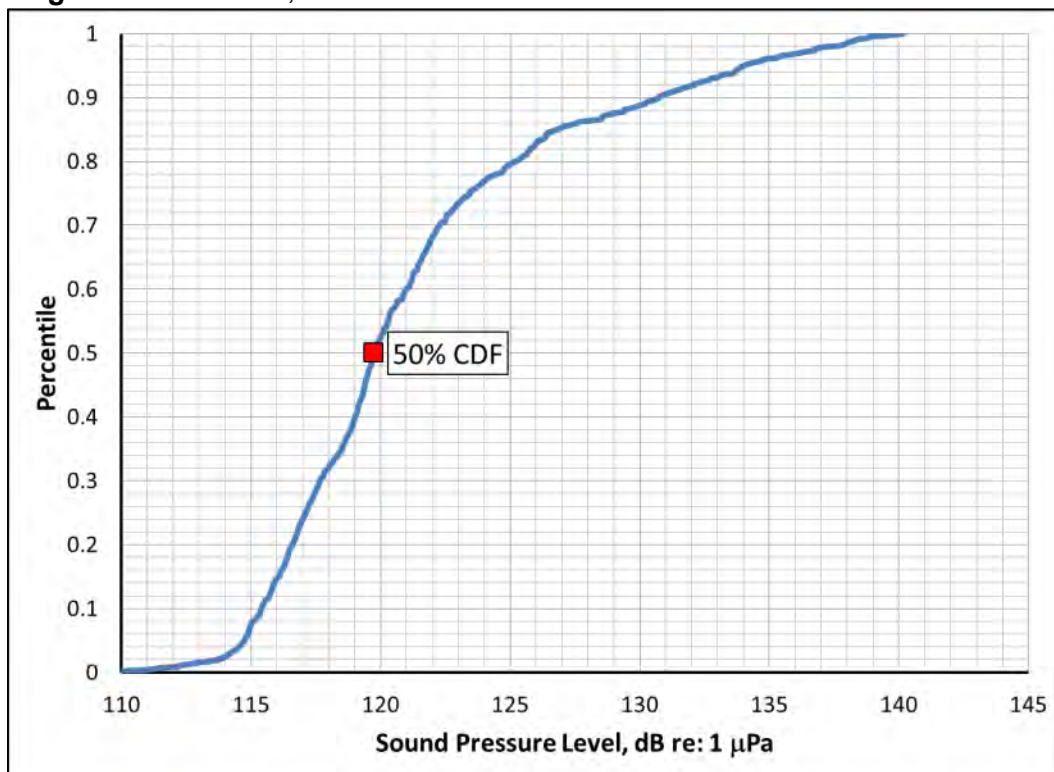
**Figure 7.4** CDF Plot, 150 Hz - 20 kHz



Source: The Greenbusch Group, Inc.

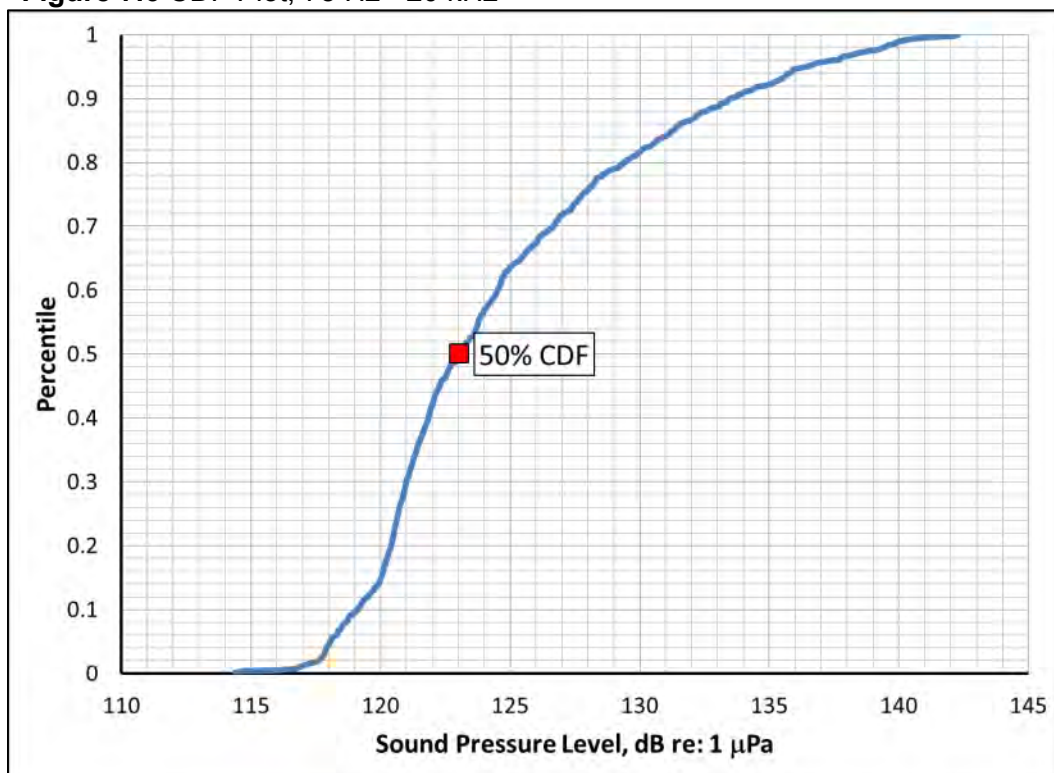


**Figure 7.5** CDF Plot, 200 Hz - 20 kHz



Source: The Greenbusch Group, Inc.

**Figure 7.6** CDF Plot, 75 Hz - 20 kHz



Source: The Greenbusch Group, Inc.

The range, average and standard deviation (SD) of background sound levels measured in January 2015, as well as the long term daytime sound levels collected by WSDOT in April 2011 are presented for each functional hearing group in Table 7.2.

**Table 7.2** Average Daytime Background Sound Levels in Elliott Bay, dB re: 1  $\mu$ Pa

Functional Hearing Group	Frequency Range	Background Sound Levels						
		Short Term (Greenbusch 2015)				WSDOT (2011)		
		Min	Max	SD	Average <sup>1</sup>	Min	Max	Average <sup>1</sup>
Low-Frequency Cetaceans	7 Hz – 20 kHz	122	170	9	<b>140</b>	-	-	<b>130</b>
Mid-Frequency Cetaceans	150 Hz – 20 kHz	111	141	6	<b>120</b>	103	143	<b>124</b>
High-Frequency Cetaceans	200 Hz – 20 kHz	110	140	6	<b>120</b>	-	-	<b>124</b>
Pinnipeds	75 Hz – 20 kHz	114	142	6	<b>123</b>	104	144	<b>127</b>

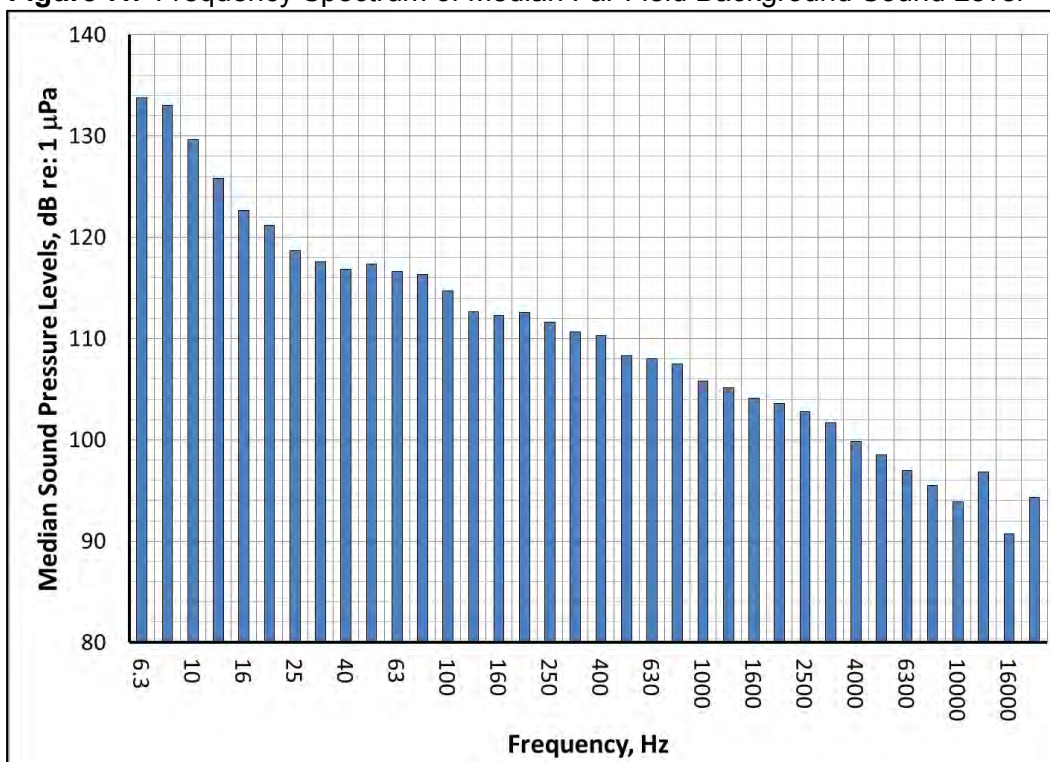
Note: "-" indicates data is unknown

1. The median was used to report the average background sound levels

Source: The Greenbusch Group, WSDOT report titled "Compendium of Background Sound Levels for Ferry Terminals in Puget Sound" issued April, 2014

The underwater 1/3 octave frequency spectrum of the median far field background sound level measured by Greenbusch is provided in Figure 7.7.

**Figure 7.7** Frequency Spectrum of Median Far Field Background Sound Level

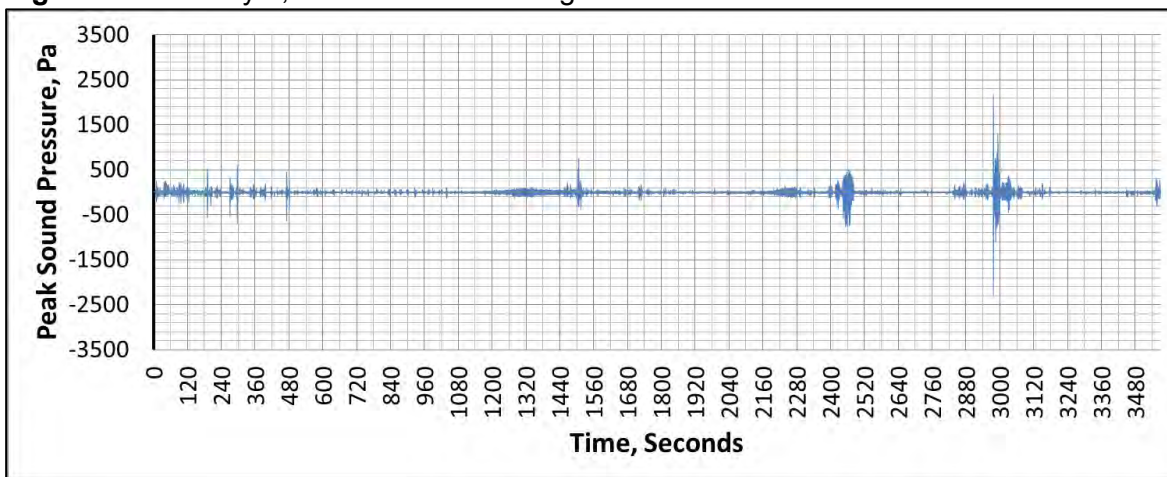


Source: The Greenbusch Group, Inc.

Waveforms of the 1 hour far field background sound level measurements made by Greenbusch are provided in Figure 7.8 through Figure 7.10.

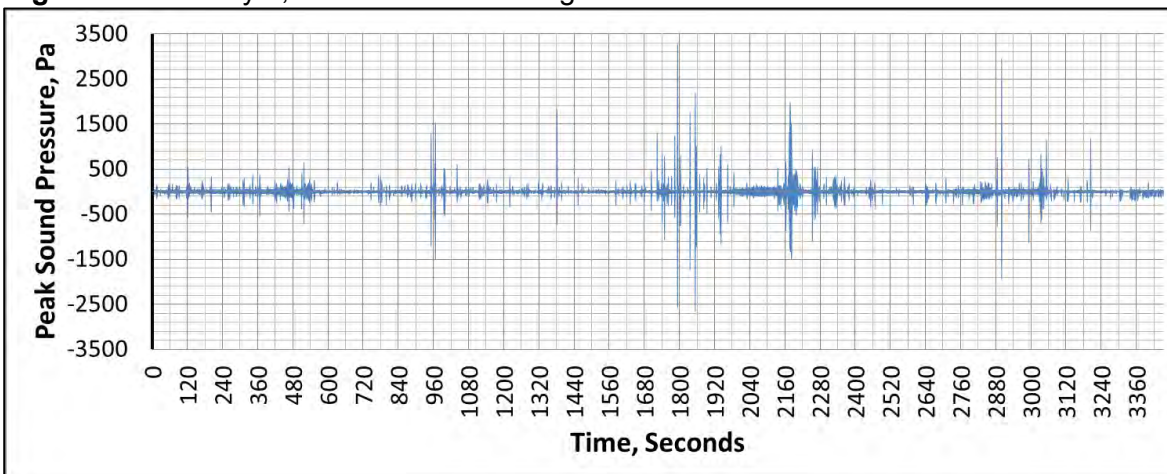


**Figure 7.8** January 3, 2015 Far Field Background Waveform



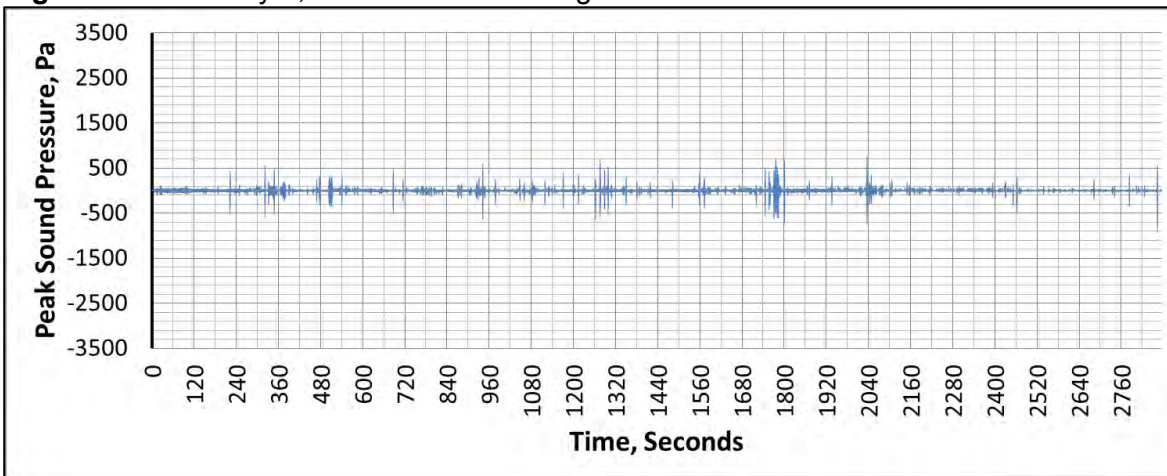
Source: The Greenbusch Group, Inc.

**Figure 7.9** January 7, 2015 Far Field Background Waveform



Source: The Greenbusch Group, Inc.

**Figure 7.10** January 8, 2015 Far Field Background Waveform



Source: The Greenbusch Group, Inc.

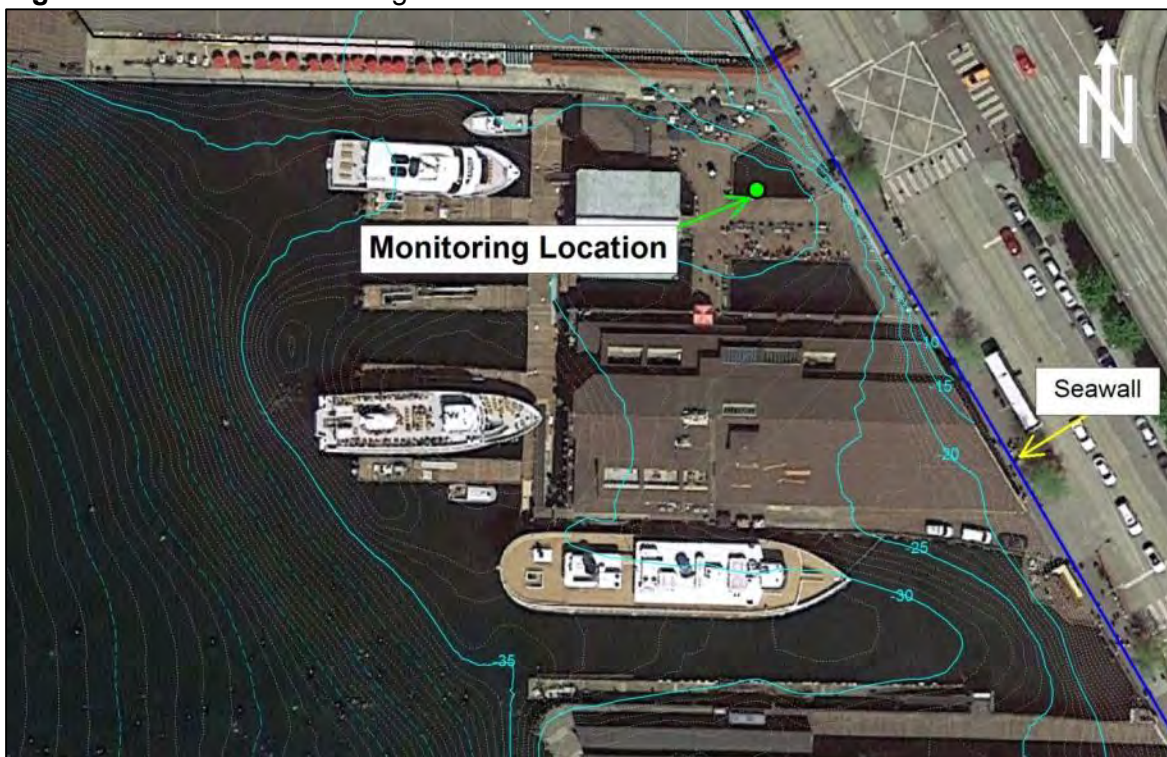
As shown in Table 7.2, the average background sound levels collected in January 2015 are within the range of daytime sound levels collected by WSDOT. Due to the long term nature of the WSDOT measurements, the average daytime background sound data collected by WSDOT will be used in this report to calculate the distance required for underwater RMS sound levels generated by pile driving activities to attenuate to background sound levels.

## **7.2 Near Shore Background Sound Levels**

Long term background sound levels were measured approximately 10 meters from the location where monitored piles were installed. These measurements were made at the request of NOAA to ensure that background sound levels near the monitored piles did not influence the measurements of the pile driving.

Continuous sound level measurements were made between December 16 and December 17, 2014 as well as between December 20 and December 25, 2014. The hydrophone was positioned at mid-water depth and secured to a pier. Figure 7.11 shows the near shore background measurement location.

**Figure 7.11** Near Shore Background Measurement Location



Source: The Greenbusch Group, Inc.

Equipment used to collect long-term near shore background sound data is presented in Figure 7.12.

**Figure 7.12** Near Shore Background Sound Measurement Equipment

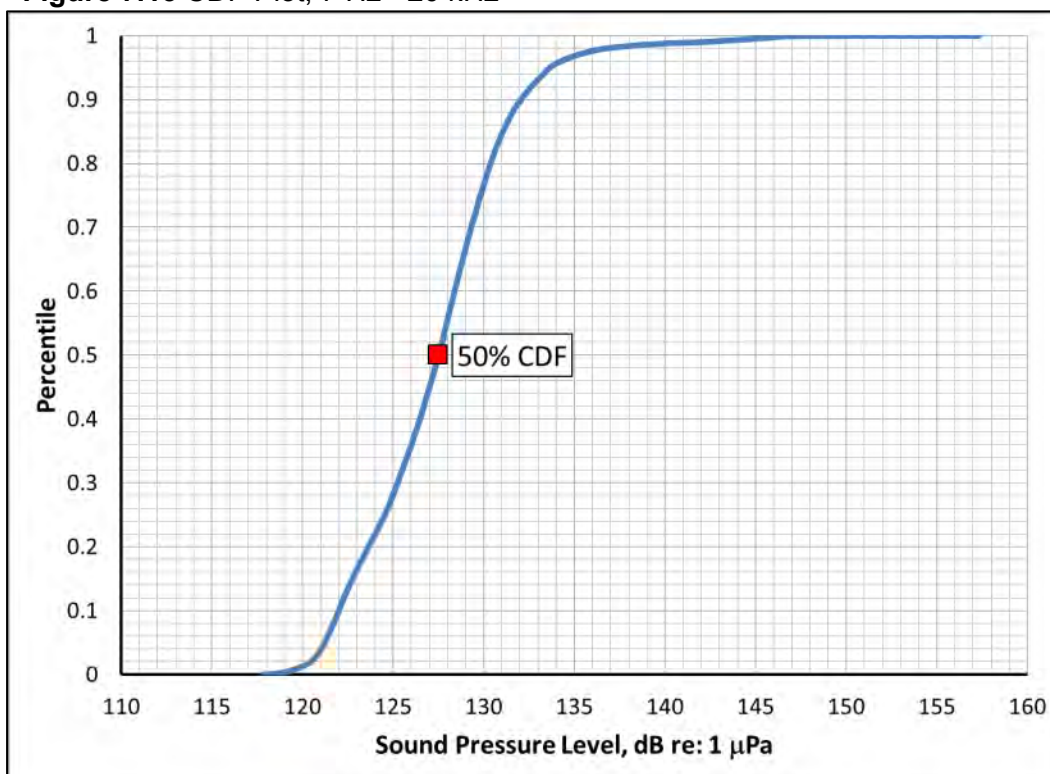


Source: The Greenbusch Group, Inc.

10-second daytime RMS values were used from the long-term near shore measurements to generate CDF plots for each marine mammal functional hearing group. These CDF plots are presented in Figure 7.13 through Figure 7.16.

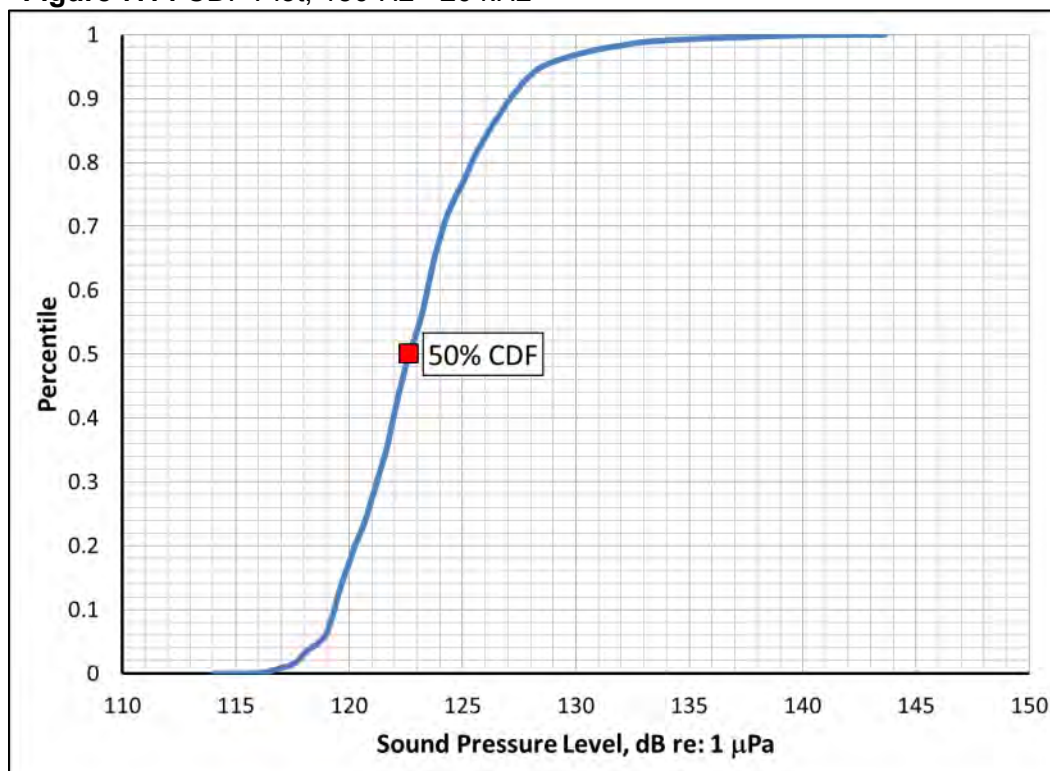


**Figure 7.13** CDF Plot, 7 Hz - 20 kHz



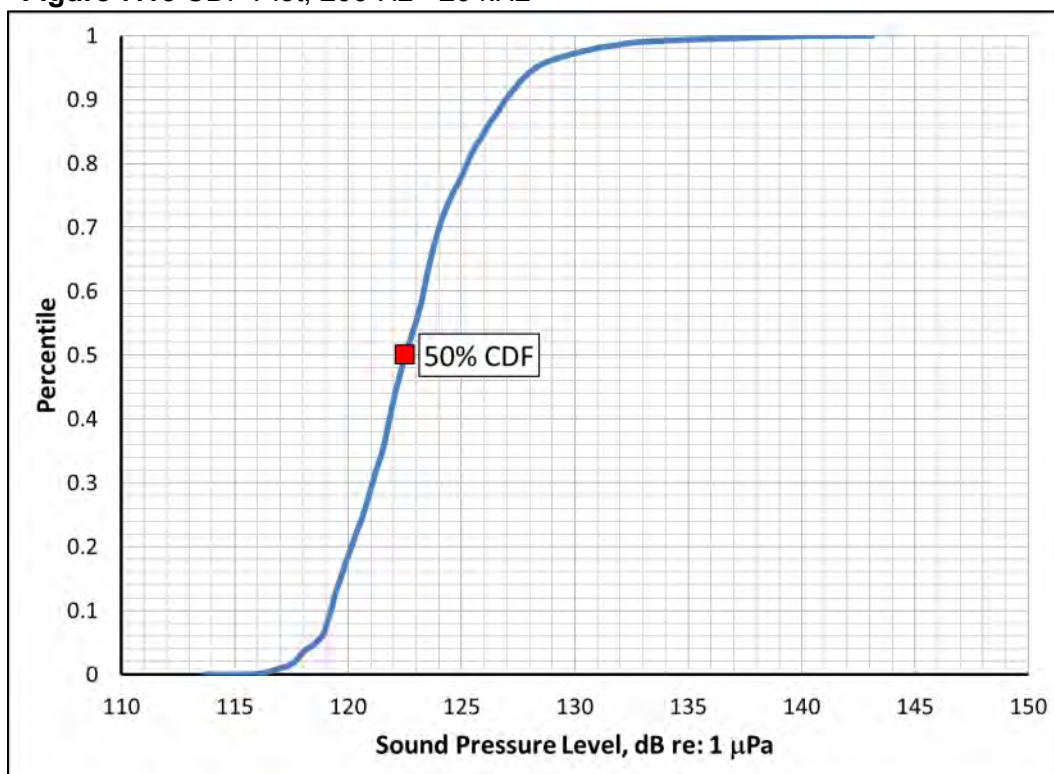
Source: The Greenbusch Group, Inc.

**Figure 7.14** CDF Plot, 150 Hz - 20 kHz



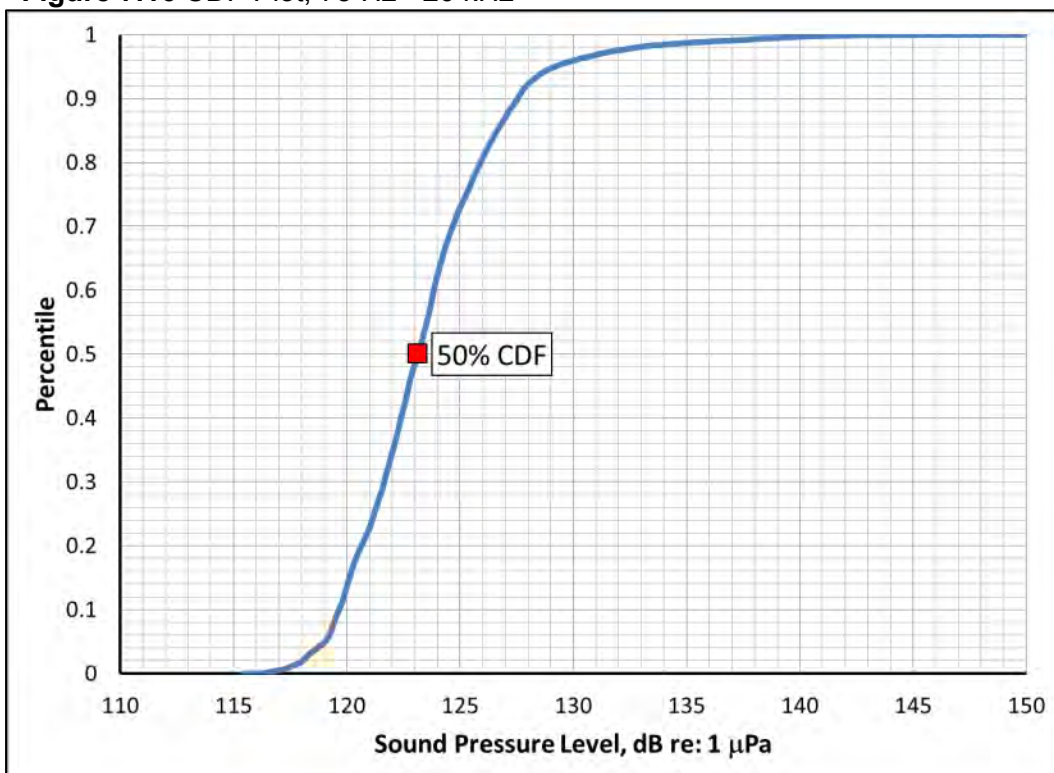
Source: The Greenbusch Group, Inc.

**Figure 7.15** CDF Plot, 200 Hz - 20 kHz



Source: The Greenbusch Group, Inc.

**Figure 7.16** CDF Plot, 75 Hz - 20 kHz



Source: The Greenbusch Group, Inc.

The range, average and standard deviation (SD) of daytime background sound levels for each marine mammal functional hearing group calculated from near shore background sound data is presented in Table 7.3 below.

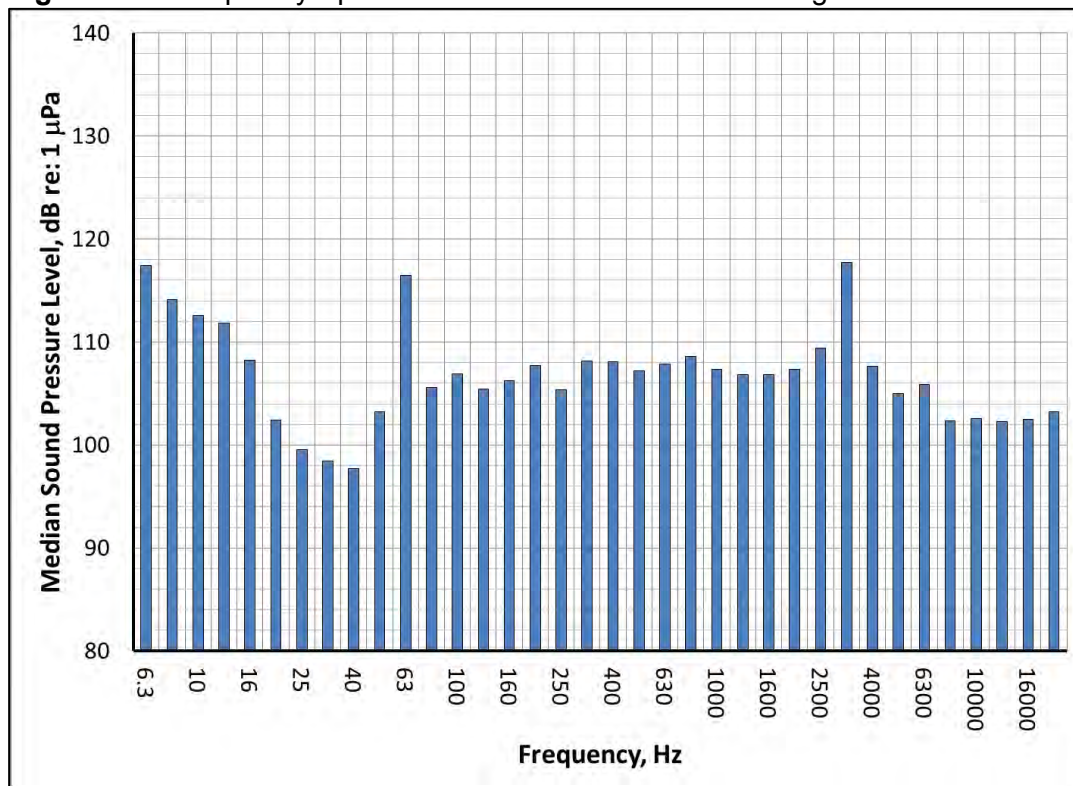
**Table 7.3** Average Daytime Near Shore Background Sound Levels, dB re: 1  $\mu$ Pa

Functional Hearing Group	Frequency Range	Background Sound Levels (Greenbusch 2015)			
		Min	Max	SD	Average <sup>1</sup>
Low-Frequency Cetaceans	7 Hz – 20 kHz	118	157	4	<b>128</b>
Mid-Frequency Cetaceans	150 Hz – 20 kHz	114	144	3	<b>123</b>
High-Frequency Cetaceans	200 Hz – 20 kHz	114	143	3	<b>123</b>
Pinnipeds	75 Hz – 20 kHz	115	150	3	<b>123</b>

1. The median was used to report the average background sound levels  
Source: The Greenbusch Group, Inc.

The underwater 1/3 octave frequency spectrum of the median near shore background sound level is provided in Figure 7.17 below.

**Figure 7.17** Frequency Spectrum of Median Near Shore Background Sound Level



Source: The Greenbusch Group, Inc.

The data gathered from near shore and far field measurement in 2015 suggest that current background sound levels in Elliott Bay are consistent with the background sound levels measured by WSDOT in 2011.

## **8.0 VIBRATORY SHEET PILES ANALYSIS AND RESULTS**

Airborne and underwater sound level measurements were made on October 30 and 31, 2014 and November 7, 2014 of the first five unobstructed steel sheet piles driven with a vibratory hammer as required by the Project's ESA and MMPA consultation.

Hydroacoustic data collected during vibratory installation of the steel sheet piles was analyzed to determine the range, average and standard deviation of 10-second RMS, peak and SEL values for each marine mammal functional hearing group. Periods during the pile drive when pile installation was not occurring under full power are excluded from the analysis. Ramp-up procedures were used at the start of each day and after breaks of more than one hour. However, only one of the monitored vibratory piles, vibratory sheet pile 1, met these timing requirements.

Data was analyzed for each functional hearing group by applying a band pass filter to remove frequencies from the signal that are not included in the functional hearing group being analyzed. SEL values were calculated using 1-second RMS values.

Reported maximum and minimum values are the maximum or minimum value from either of the two hydrophones. The standard deviation was calculated using decibel values. Average sound levels were calculated using the mean sound pressure from each hydrophone, converted to decibels and taking the logarithmic average of the two values.

A summary of underwater sound levels produced by the vibratory installation of the first five unobstructed steel sheet piles is provided in Table 8.1.

**Table 8.1** Underwater Sound Levels from Vibratory Pile Driving, dB re: 1  $\mu$ Pa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-1	7 Hz-20 kHz	171	190	5	<b>181</b>	155	169	4	<b>163</b>	148	169	4	<b>164</b>
	75 Hz-20 kHz	171	190	4	<b>181</b>	155	169	4	<b>163</b>	147	169	4	<b>164</b>
	150 Hz-20 kHz	170	190	4	<b>181</b>	155	168	4	<b>163</b>	147	169	4	<b>163</b>
	200 Hz-20 kHz	171	190	4	<b>181</b>	155	168	4	<b>163</b>	147	168	4	<b>163</b>
VIB-2	7 Hz-20 kHz	166	182	4	<b>174</b>	144	164	3	<b>156</b>	148	166	3	<b>157</b>
	75 Hz-20 kHz	166	182	4	<b>173</b>	144	164	4	<b>156</b>	146	165	3	<b>156</b>
	150 Hz-20 kHz	166	182	4	<b>173</b>	143	163	4	<b>156</b>	146	164	3	<b>156</b>
	200 Hz-20 kHz	166	182	4	<b>173</b>	143	163	4	<b>155</b>	146	164	3	<b>156</b>
VIB-3	7 Hz-20 kHz	177	185	2	<b>182</b>	159	168	2	<b>166</b>	153	168	2	<b>166</b>
	75 Hz-20 kHz	177	185	2	<b>182</b>	159	168	2	<b>165</b>	153	168	2	<b>166</b>
	150 Hz-20 kHz	176	185	2	<b>182</b>	159	168	2	<b>165</b>	150	168	3	<b>165</b>
	200 Hz-20 kHz	175	185	2	<b>182</b>	158	168	2	<b>165</b>	150	168	3	<b>165</b>
VIB-4	7 Hz-20 kHz	180	195	3	<b>186</b>	163	174	2	<b>168</b>	146	175	3	<b>168</b>
	75 Hz-20 kHz	180	194	3	<b>186</b>	163	174	2	<b>168</b>	146	175	3	<b>168</b>
	150 Hz-20 kHz	181	193	3	<b>186</b>	163	174	2	<b>168</b>	146	175	3	<b>168</b>
	200 Hz-20 kHz	180	193	3	<b>186</b>	163	174	2	<b>168</b>	146	175	3	<b>168</b>
VIB-5	7 Hz-20 kHz	166	190	3	<b>183</b>	142	171	3	<b>167</b>	149	172	3	<b>167</b>
	75 Hz-20 kHz	167	190	3	<b>183</b>	142	171	4	<b>167</b>	149	172	3	<b>167</b>
	150 Hz-20 kHz	167	190	3	<b>183</b>	142	171	3	<b>167</b>	149	172	3	<b>167</b>
	200 Hz-20 kHz	167	190	3	<b>183</b>	142	171	3	<b>167</b>	148	172	3	<b>167</b>

Source: The Greenbusch Group, Inc.

Airborne sound data collected during vibratory installation of the steel sheet piles was analyzed to determine the range and average of unweighted 10-second RMS values while piles were installed under full power. These 10-second RMS values were calculated over a frequency range of 10 Hz to 20 kHz.

A summary of airborne sound levels generated by vibratory pile driving activities is provided in Table 8.2 below.

**Table 8.2** Airborne Sound Levels from Vibratory Pile Driving, dB re: 20  $\mu$ Pa

Pile ID	Minimum	Maximum	Average
VIB-1	98	112	<b>108</b>
VIB-2	99	116	<b>109</b>
VIB-3	101	112	<b>109</b>
VIB-4	101	111	<b>109</b>
VIB-5	102	116	<b>111</b>

Source: The Greenbusch Group, Inc.



## 8.1 Vibratory Sheet Pile 1

The first unobstructed steel sheet pile installed with a vibratory hammer was monitored on October 30, 2014. The drive began at 1:25 PM and included a ramp-up process as required in the Project's ESA and MMPA consultation. Table 8.3 below presents the distance between the sheet pile and the water's edge, water depth, depth into the substrate the pile was driven and the total drive time.

**Table 8.3** Vibratory Sheet Pile 1 Pile Information, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Drive Time (minutes)
VIB-1	10/30/14	None	3	20	40	16

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Logs

Airborne sound levels were measured 50 feet from the sheet pile at an elevation of 7 feet above the pier. Hydrophones were located 34 feet from the pile with an unobstructed path between the pile and the hydrophones. Table 8.4 below presents the water depth at the hydrophone location, hydrophone depth, and distance between the hydrophones, as well as the distance from the hydrophones to the pile.

**Table 8.4** Vibratory Sheet Pile 1 Hydrophone Location Information, Feet

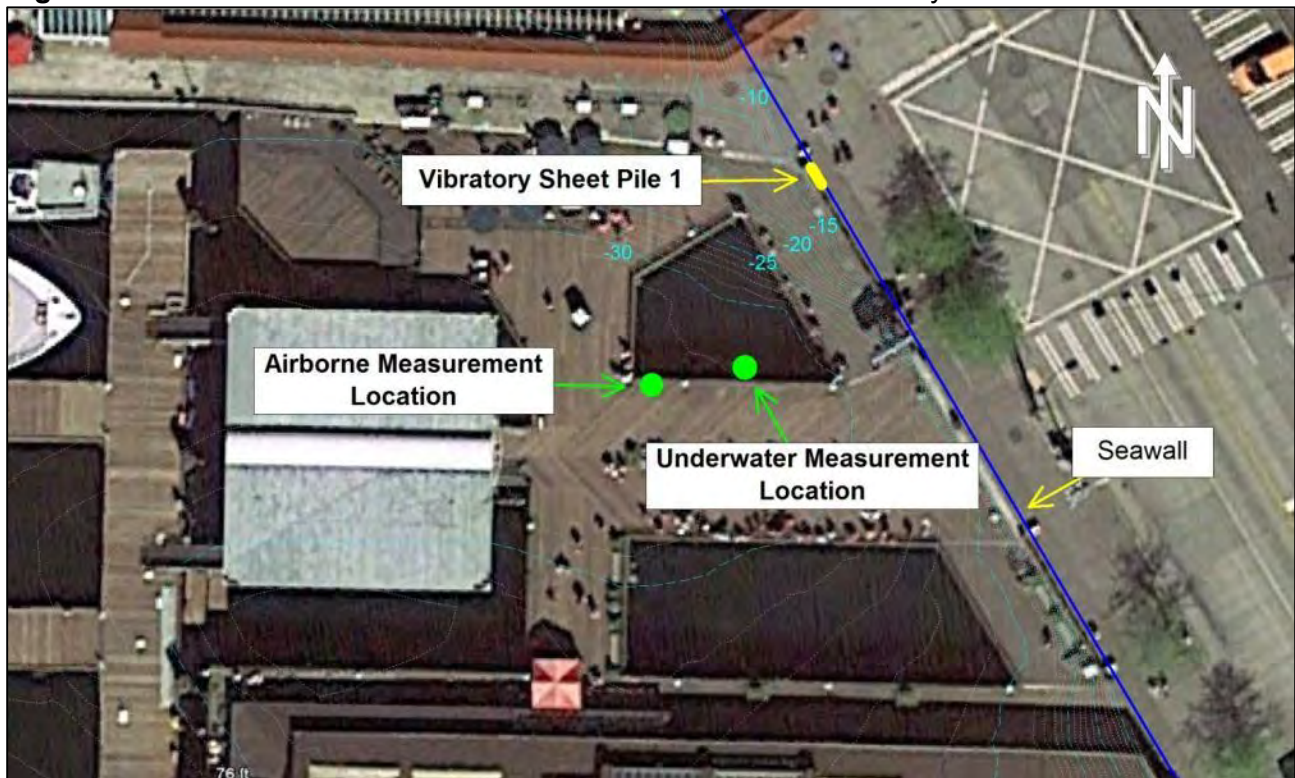
Pile ID	Depth at Measurement Location <sup>1</sup>	Hydrophone	Hydrophone Depth	Distance between Hydrophones	Distance to Pile
VIB-1	35	Upper	3	28	34
		Lower	32		

1. Depth at start of pile drive

Source: The Greenbusch Group, Inc. NOAA Station #9447130

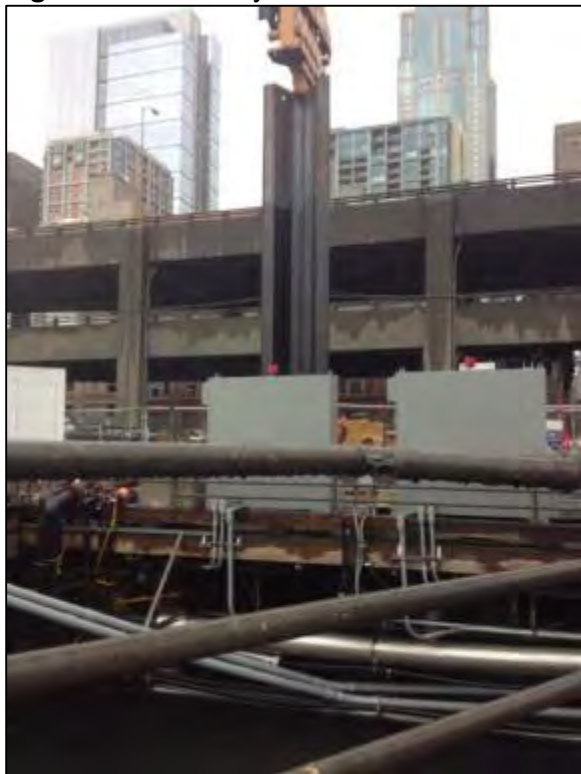
The locations of vibratory sheet pile 1, hydrophones and airborne sound monitoring equipment are illustrated in Figure 8.1. Photos showing vibratory sheet pile 1 and the location of the hydrophones are provided in Figure 8.2 and Figure 8.3.

**Figure 8.1** Sheet Pile Location and Measurement Locations of Vibratory Sheet Pile 1



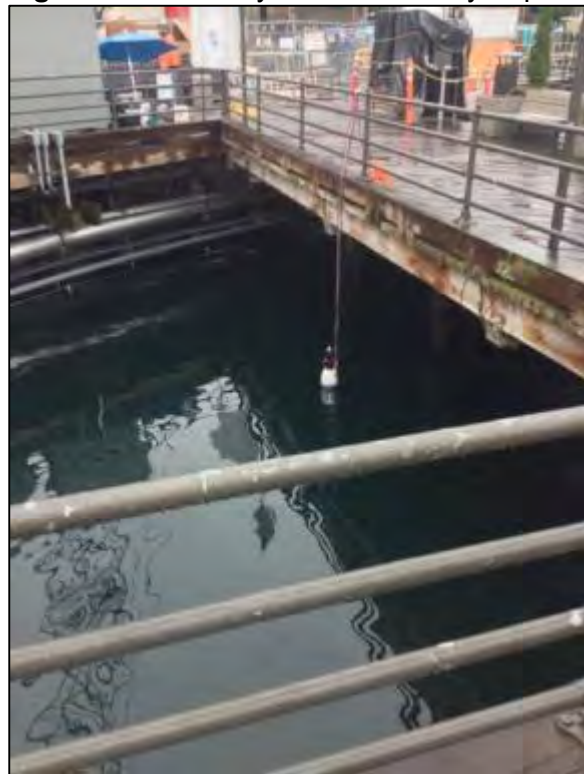
Source: The Greenbusch Group, Inc.

**Figure 8.2** Vibratory Sheet Pile 1



Source: The Greenbusch Group, Inc.

**Figure 8.3** Vibratory Sheet Pile 1 Hydrophone



Source: The Greenbusch Group, Inc.

### 8.1.1 Underwater Measurement Results

Hydroacoustic data collected during the installation of the first unobstructed steel sheet pile driven with a vibratory hammer was analyzed to determine the range, average and standard deviation of the peak, 10-second RMS and SEL values for each marine mammal functional hearing group during the ramp-up as well as full power driving.

**Table 8.5** Vibratory Sheet Pile 1 Underwater Sound Levels, dB re: 1  $\mu$ Pa

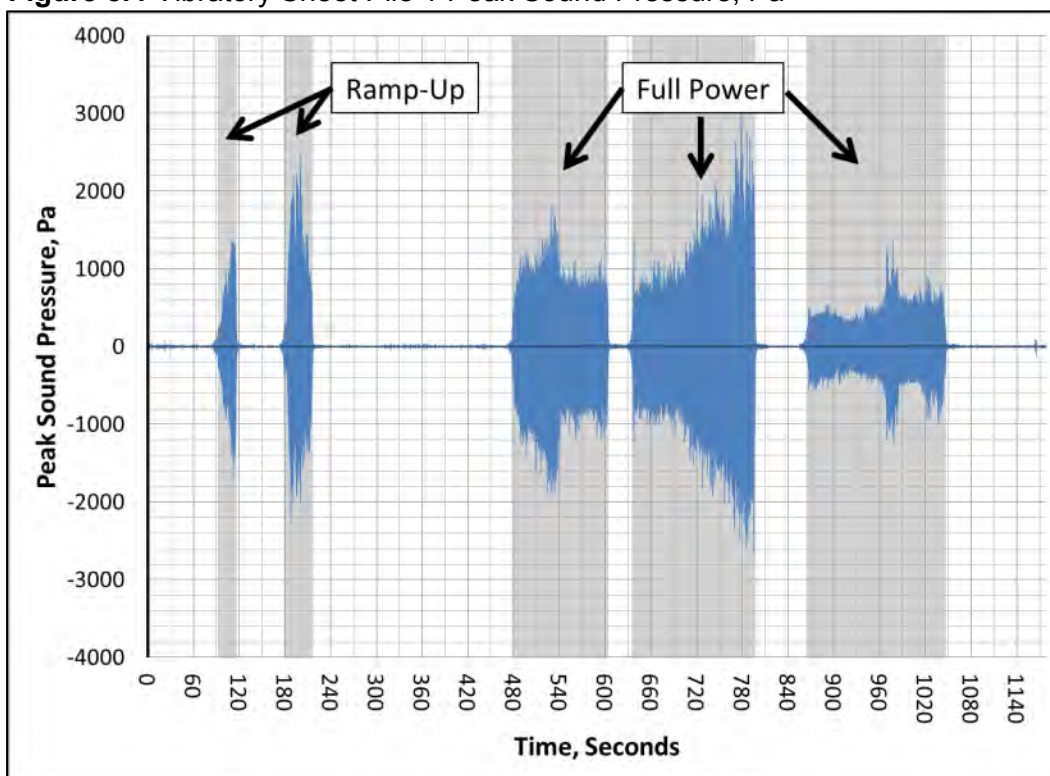
Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-1	<i>Ramp Up</i>												
	7 Hz-20 kHz	179	190	3	<b>185</b>	160	168	3	<b>165</b>	153	170	4	<b>165</b>
	75 Hz-20 kHz	178	190	3	<b>185</b>	161	167	2	<b>165</b>	154	169	4	<b>165</b>
	150 Hz-20 kHz	179	190	4	<b>185</b>	161	167	3	<b>164</b>	153	169	4	<b>165</b>
	200 Hz-20 kHz	179	187	3	<b>184</b>	160	165	2	<b>163</b>	153	169	4	<b>165</b>
	<i>Full Power</i>												
	7 Hz-20 kHz	171	190	5	<b>181</b>	155	169	4	<b>163</b>	148	169	4	<b>164</b>
	75 Hz-20 kHz	171	190	4	<b>181</b>	155	169	4	<b>163</b>	147	169	4	<b>164</b>
	150 Hz-20 kHz	170	190	4	<b>181</b>	155	168	4	<b>163</b>	147	169	4	<b>163</b>
	200 Hz-20 kHz	171	190	4	<b>181</b>	155	168	4	<b>163</b>	147	168	4	<b>163</b>

Source: The Greenbusch Group, Inc.

The results presented in Table 8.5 were generated by analyzing underwater sound levels produced while pile installation was occurring under full power as well as during ramp-up. Periods when the vibratory hammer was not operating were excluded from the analysis. The shaded regions of Figure 8.4 represent the periods when data analysis was performed.

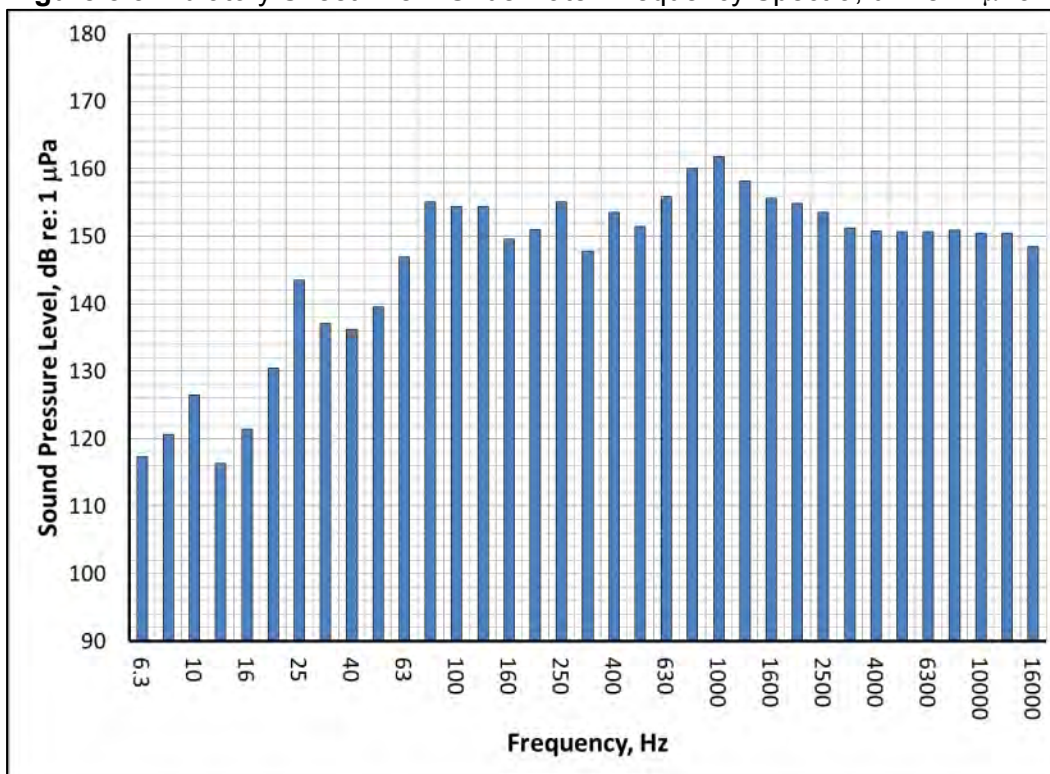
The underwater frequency spectrum associated with the highest 10-second RMS level measured during the installation of vibratory pile 1 is shown in Figure 8.5.

**Figure 8.4** Vibratory Sheet Pile 1 Peak Sound Pressure, Pa



Source: The Greenbusch Group, Inc.

**Figure 8.5** Vibratory Sheet Pile 1 Underwater Frequency Spectra, dB re: 1  $\mu$ Pa



Source: The Greenbusch Group, Inc.



### 8.1.2 Airborne Measurement Results

Airborne sound data collected during the drive of the first unobstructed sheet pile driven with a vibratory hammer was analyzed to determine range and average of 10-second RMS values between 10 Hz and 20 kHz during the ramp-up as well as full power driving.

**Table 8.6** Vibratory Sheet Pile 1 Airborne Sound Levels, dB re: 20  $\mu$ Pa

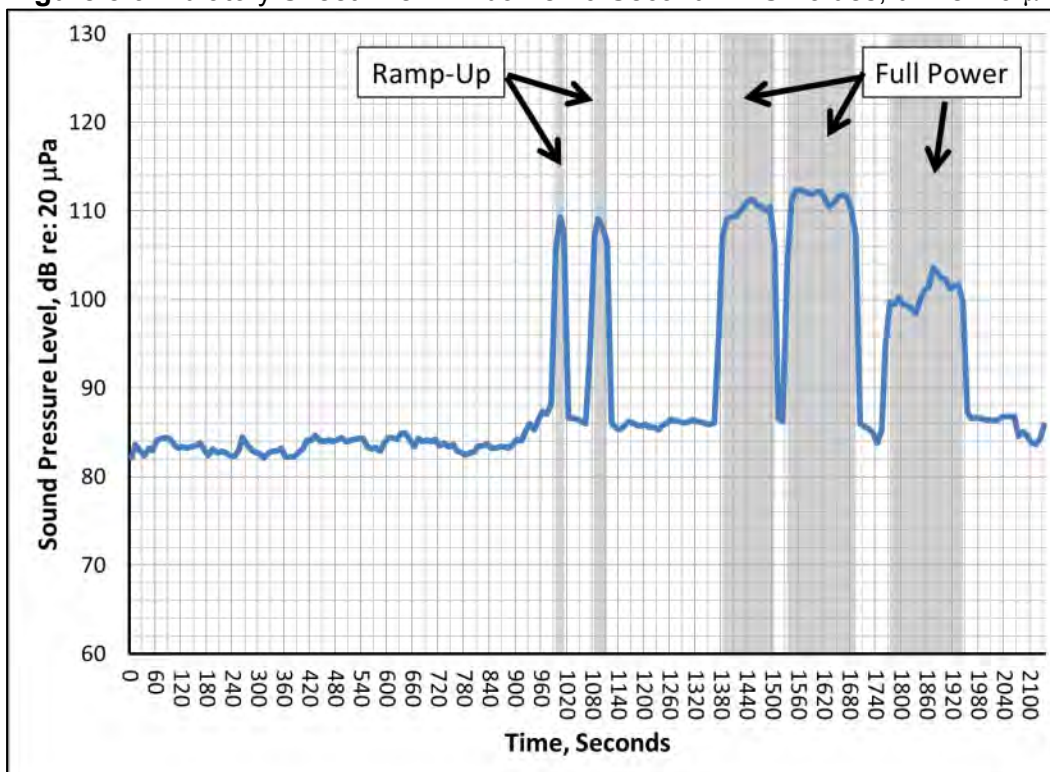
Pile ID	Minimum	Maximum	Average
VIB-1	<i>Ramp-Up</i>		
	106	109	<b>108</b>
	<i>Full Power</i>		
	98	112	<b>108</b>

Source: The Greenbusch Group, Inc.

The results presented in Table 8.6 were generated by analyzing airborne sound data collected during periods when pile installation was taking place under full power and during ramp-up. Periods when the vibratory hammer was not operating were excluded from the analysis. The shaded regions of Figure 8.6 represent the times when data analysis was performed. Figure 8.6 also presents the airborne 10-second RMS values measured over the entire drive of vibratory sheet pile 1.

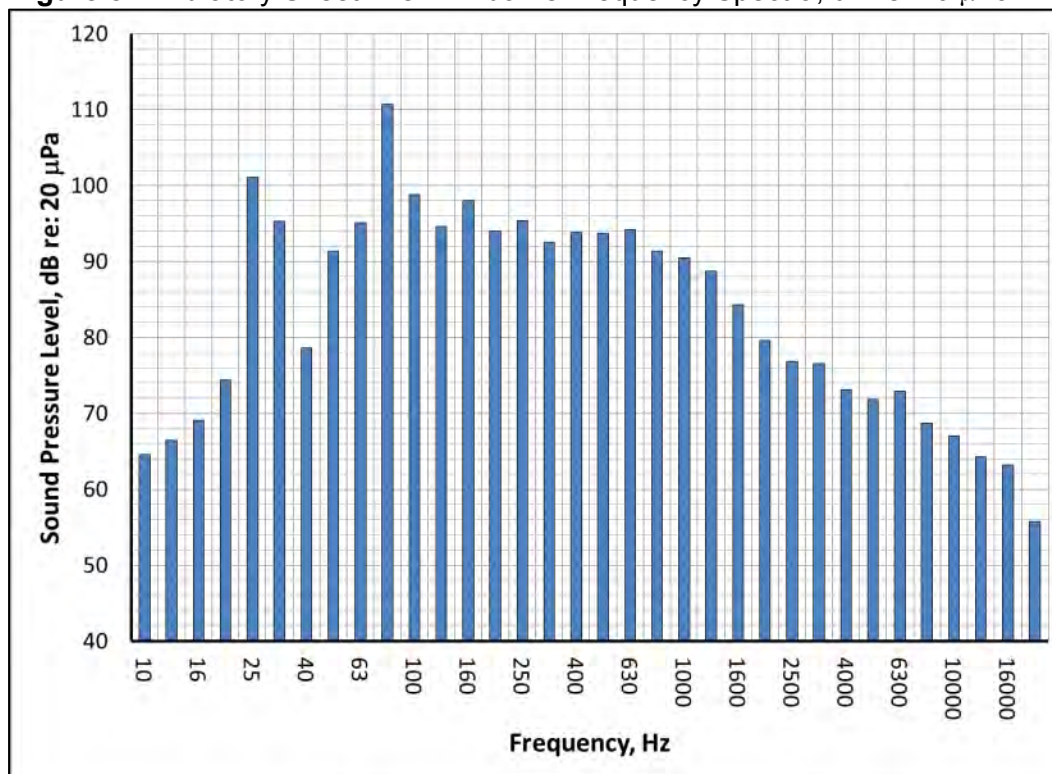
Figure 8.7 presents the airborne frequency spectrum associated with the highest 10-second RMS level measured during the drive of vibratory sheet pile 1.

**Figure 8.6** Vibratory Sheet Pile 1 Airborne 10-Second RMS Values, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

**Figure 8.7** Vibratory Sheet Pile 1 Airborne Frequency Spectra, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

## 8.2 Vibratory Sheet Pile 2

The second unobstructed steel sheet pile driven with a vibratory hammer was monitored on October 30, 2014. The drive began at 4:35 PM and did not include a ramp-up. Table 8.7 below presents the distance between the sheet pile and the water's edge, water depth, depth into the substrate the pile was driven and the total drive time.

**Table 8.7** Vibratory Sheet Pile 2 Pile Information, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Drive Time (minutes)
VIB-2	10/30/14	None	3	20	40	16

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Logs

Airborne sound levels were measured 50 feet from the sheet pile at an elevation of 7 feet above the pier. Hydrophones were located 33 feet from the pile with an unobstructed path between the pile and the hydrophones. Table 8.8 below presents the water depth at the hydrophone location, hydrophone depth, and distance between the hydrophones as well as the distance between the hydrophones and the pile.

**Table 8.8** Vibratory Sheet Pile 2 Hydrophone Location Information, Feet

Pile ID	Depth at Measurement Location <sup>1</sup>	Hydrophone	Hydrophone Depth	Distance between Hydrophones	Distance to Pile
VIB-2	32	Upper	3	26	33
		Lower	29		

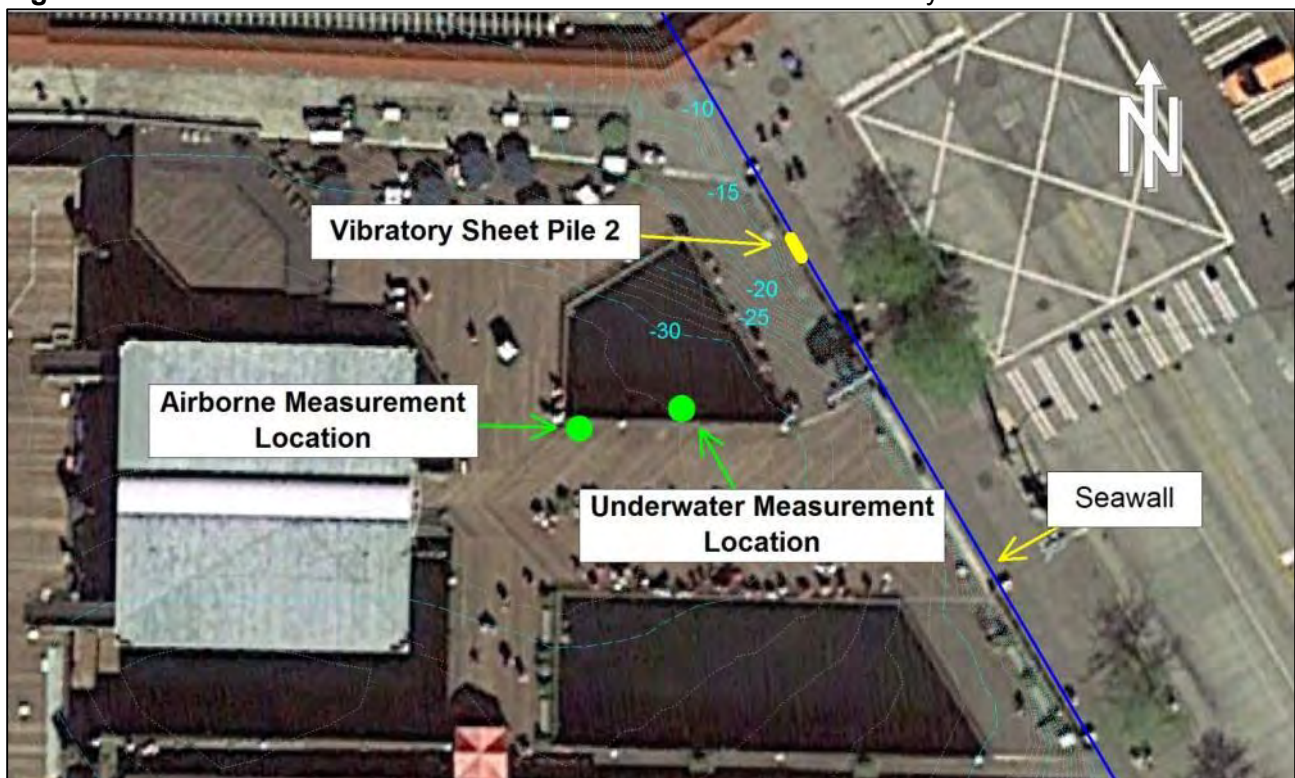
1. Depth at start of pile drive

Source: The Greenbusch Group, Inc. NOAA Station #9447130

The locations of the sheet pile, hydrophones and airborne sound monitoring equipment are illustrated in Figure 8.8. Photos showing the location of vibratory sheet pile 2 and the location of the hydrophones are provided in Figure 8.9 and Figure 8.10.



**Figure 8.8** Sheet Pile Location and Measurement Locations of Vibratory Sheet Pile 2



Source: The Greenbusch Group, Inc.

**Figure 8.9** Vibratory Sheet Pile 2



Source: The Greenbusch Group, Inc.

**Figure 8.10** Vibratory Sheet Pile 2 Hydrophone



Source: The Greenbusch Group, Inc.



### 8.2.1 Underwater Measurement Results

Underwater sound data collected during the installation of the second unobstructed steel sheet pile driven with a vibratory hammer was analyzed to determine the range, average and standard deviation of the peak, 10-second RMS and SEL values for each marine mammal functional hearing group during periods when the pile was driven at full power.

**Table 8.9** Vibratory Sheet Pile 2 Underwater Sound Levels, dB re: 1  $\mu$ Pa

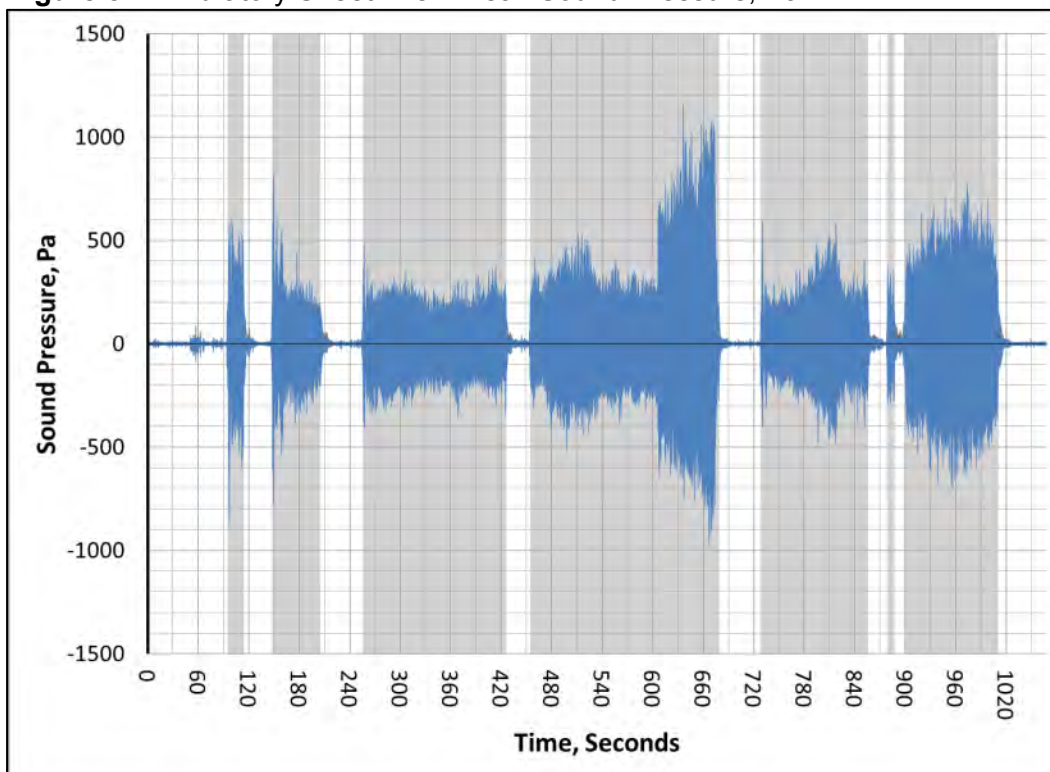
Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-2	7 Hz-20 kHz	166	182	4	<b>174</b>	144	164	3	<b>156</b>	148	166	3	<b>157</b>
	75 Hz-20 kHz	166	182	4	<b>173</b>	144	164	4	<b>156</b>	146	165	3	<b>156</b>
	150 Hz-20 kHz	166	182	4	<b>173</b>	143	163	4	<b>156</b>	146	164	3	<b>156</b>
	200 Hz-20 kHz	166	182	4	<b>173</b>	143	163	4	<b>155</b>	146	164	3	<b>156</b>

Source: The Greenbusch Group, Inc.

The hydroacoustic monitoring results shown in Table 8.9 were generated by only analyzing periods when vibratory pile driving was occurring at full power. The shaded regions of Figure 8.11 represent the periods when data analysis was performed.

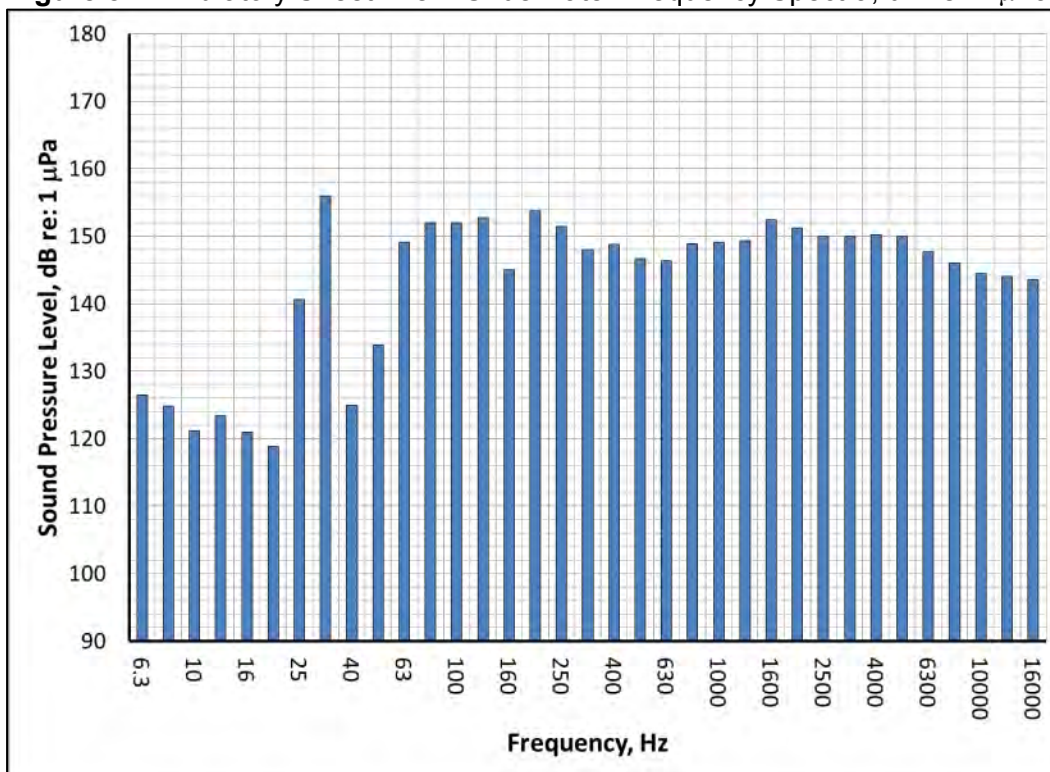
The underwater frequency spectrum associated with the highest 10-second RMS level measured during the installation of vibratory sheet pile 2 is presented in Figure 8.12.

**Figure 8.11** Vibratory Sheet Pile 2 Peak Sound Pressure, Pa



Source: The Greenbusch Group, Inc.

**Figure 8.12** Vibratory Sheet Pile 2 Underwater Frequency Spectra, dB re: 1  $\mu$ Pa



Source: The Greenbusch Group, Inc.

## 8.2.2 Airborne Measurement Results

Airborne data collected during the installation of the second unobstructed sheet pile driven using a vibratory hammer was analyzed to determine the range and average of 10-second RMS values between 10 Hz and 20 kHz during periods when pile driving was occurring under full power.

**Table 8.10** Vibratory Sheet Pile 2 Airborne Sound Levels, dB re: 20  $\mu$ Pa

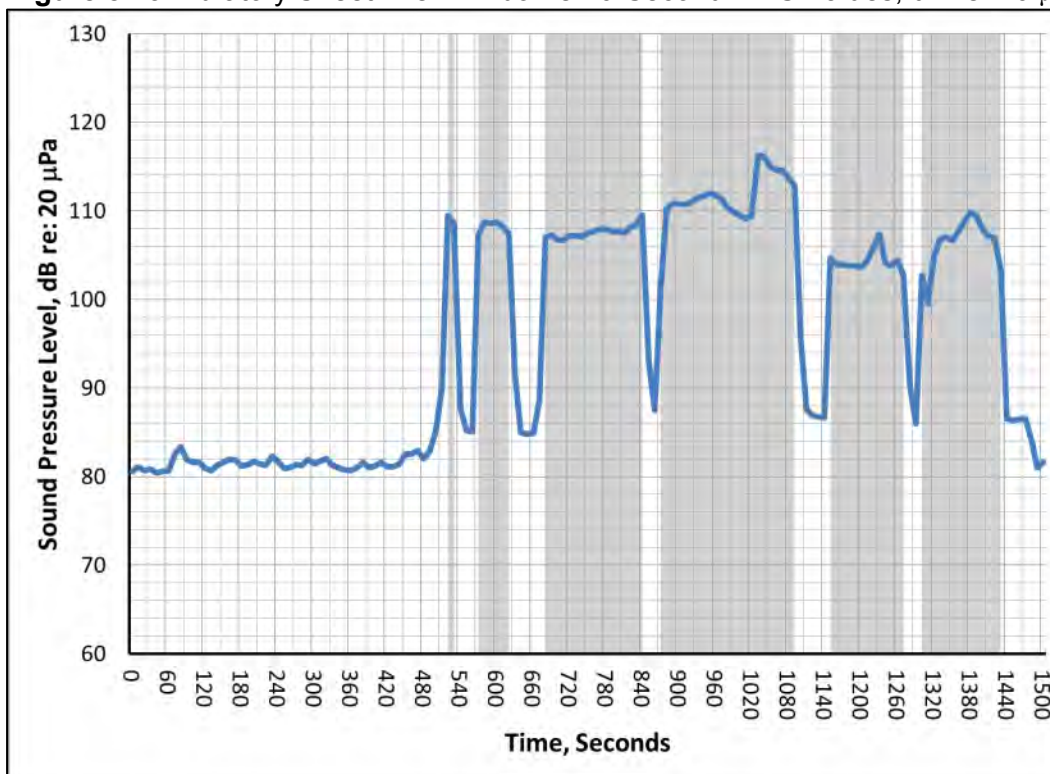
Pile ID	Minimum	Maximum	Average
VIB-2	99	116	109

Source: The Greenbusch Group, Inc.

The results presented in Table 8.10 were generated by analyzing airborne sound data collected during periods when the vibratory hammer was operating at full power. Periods when the hammer was not operating were excluded from the analysis. The shaded regions of Figure 8.13 represent periods included in the airborne noise analysis. Figure 8.13 also presents the 10-second RMS airborne sound levels measured over the entire drive of vibratory sheet pile 2.

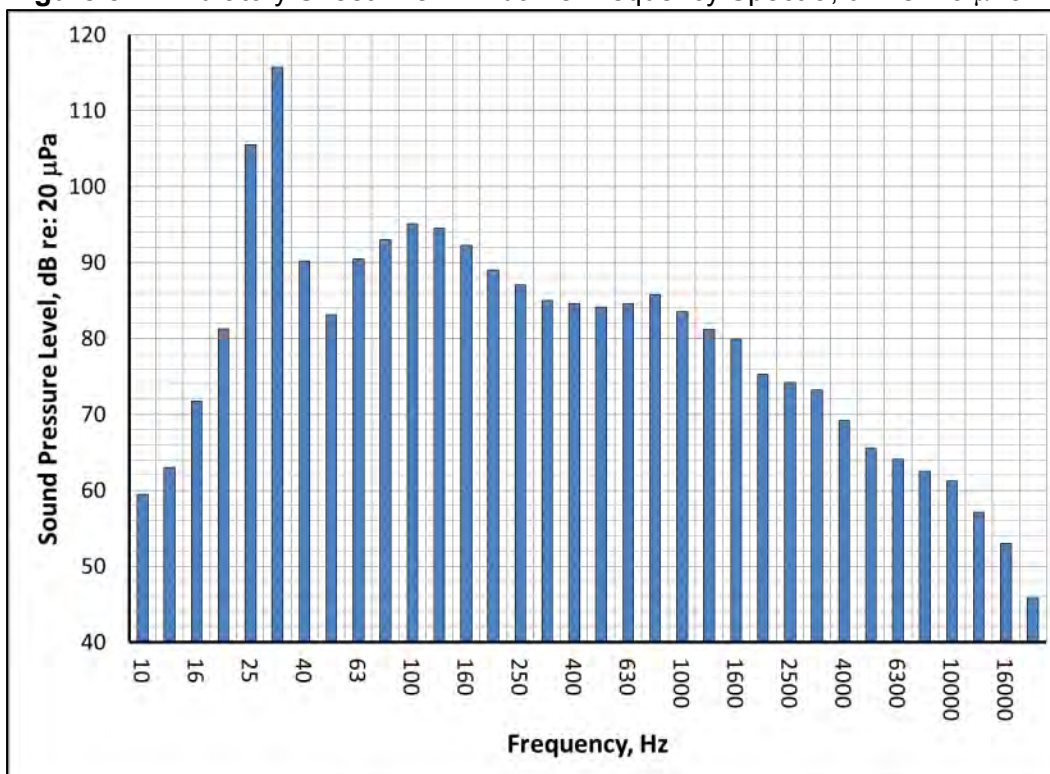
Figure 8.14 shows the airborne frequency spectrum associated with the highest 10-second RMS level measured during the installation of vibratory sheet pile 2.

**Figure 8.13** Vibratory Sheet Pile 2 Airborne 10-Second RMS Values, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

**Figure 8.14** Vibratory Sheet Pile 2 Airborne Frequency Spectra, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

### 8.3 Vibratory Sheet Pile 3

The third unobstructed steel sheet pile installed using a vibratory hammer was monitored on October 31, 2014. The drive began at 9:25 AM and did not include a ramp-up. Table 8.11 below provides the distance from the pile to the water's edge, water depth at the location of the pile, depth into the substrate the pile was driven and the duration of the drive.

**Table 8.11** Vibratory Sheet Pile 3 Pile Information, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Drive Time (minutes)
VIB-3	10/31/14	None	3	20	40	10

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Logs

Airborne sound level measurements were conducted 50 feet from vibratory sheet pile 3 at an elevation of approximately 7 feet above the pier. Hydrophones were located 33 feet from the pile with an unobstructed sound transmission path between the hydrophones and the pile. Table 8.12 presents the water depth at the hydrophones location, hydrophone depth, distance between hydrophones and the distance from the hydrophones to the pile.

**Table 8.12** Vibratory Sheet Pile 3 Hydrophone Location Information, Feet

Pile ID	Depth at Measurement Location <sup>1</sup>	Hydrophone	Hydrophone Depth	Distance between Hydrophones	Distance to Pile
VIB-3	39	Upper	3	32	33
		Lower	36		

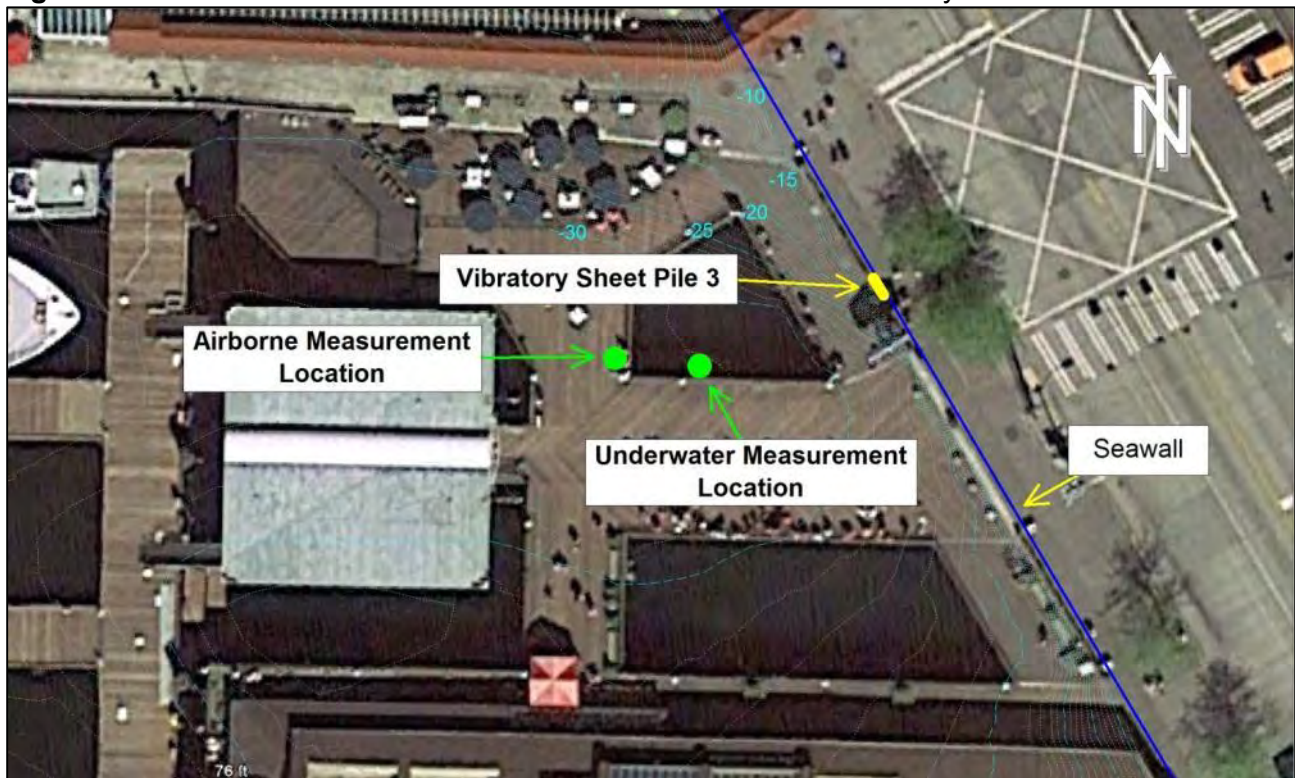
1. Depth at start of pile drive

Source: The Greenbusch Group, Inc. NOAA Station #9447130

The locations of vibratory sheet pile 3, hydrophones and airborne sound monitoring equipment are illustrated in Figure 8.15. Photos showing vibratory sheet pile 3 and the location of the hydrophones are provided in Figure 8.16 and Figure 8.17.



**Figure 8.15** Sheet Pile Location and Measurement Locations of Vibratory Sheet Pile 3



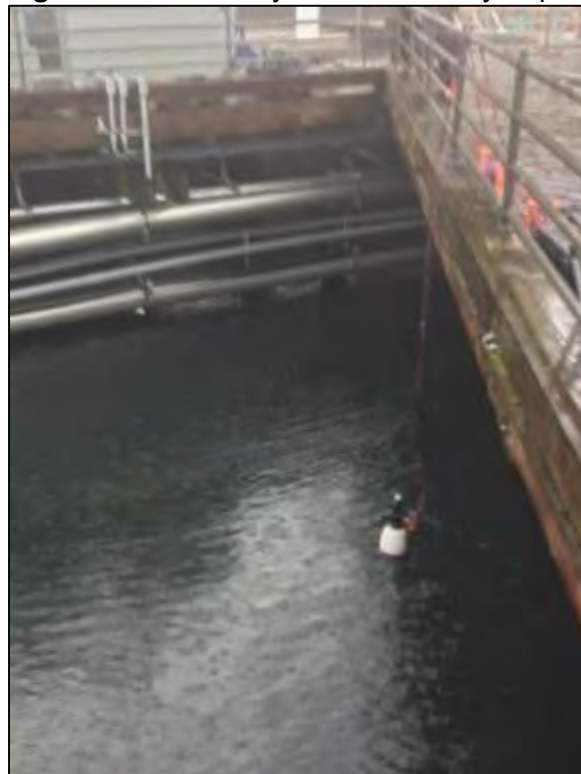
Source: The Greenbusch Group, Inc.

**Figure 8.16** Vibratory Sheet Pile 3



Source: The Greenbusch Group, Inc.

**Figure 8.17** Vibratory Sheet 3 Pile Hydrophone



Source: The Greenbusch Group, Inc.

### 8.3.1 Underwater Measurement Results

Hydroacoustic data gathered during the drive of the third unobstructed sheet pile driven using a vibratory hammer was analyzed to determine the range, average and standard deviation of the peak, 10-second RMS and SEL values for each marine mammal functional hearing group while pile driving was occurring under full power.

**Table 8.13** Vibratory Sheet Pile 3 Underwater Sound Levels, dB re: 1  $\mu$ Pa

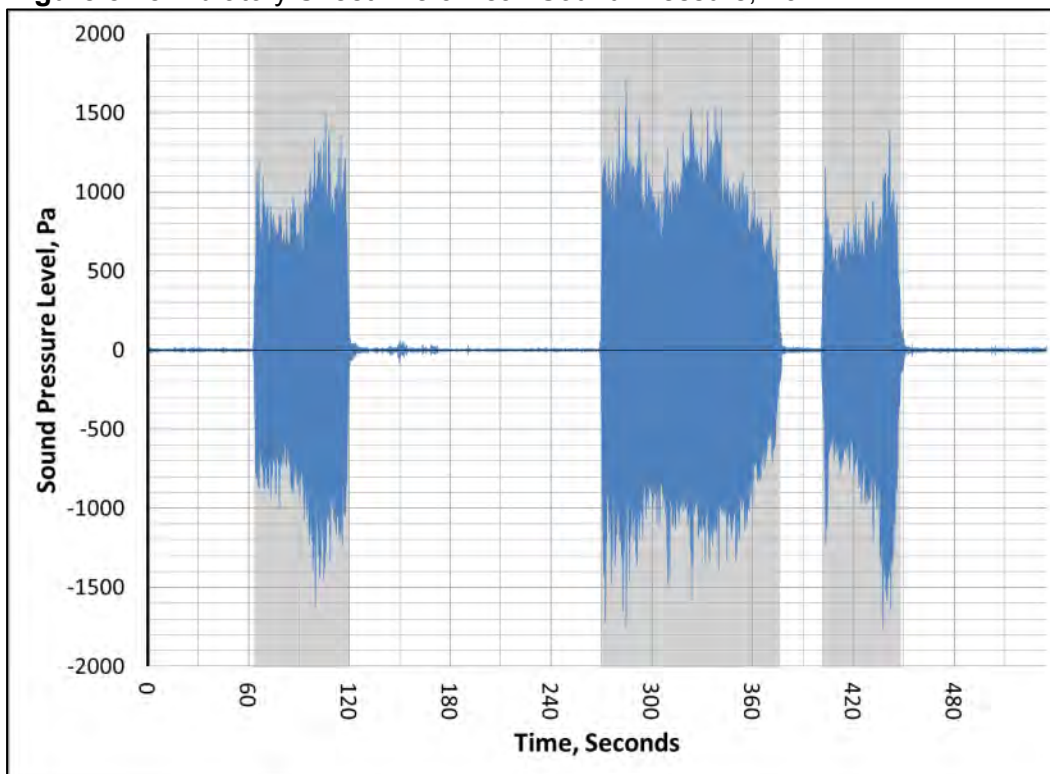
Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-3	7 Hz-20 kHz	177	185	2	<b>182</b>	159	168	2	<b>166</b>	153	168	2	<b>166</b>
	75 Hz-20 kHz	177	185	2	<b>182</b>	159	168	2	<b>165</b>	153	168	2	<b>166</b>
	150 Hz-20 kHz	176	185	2	<b>182</b>	159	168	2	<b>165</b>	150	168	3	<b>165</b>
	200 Hz-20 kHz	175	185	2	<b>182</b>	158	168	2	<b>165</b>	150	168	3	<b>165</b>

Source: The Greenbusch Group, Inc.

The hydroacoustic monitoring results presented in Table 8.13 were generated by only analyzing underwater sound data produced while pile driving was taking place under full power. Periods when the vibratory hammer was not operating were excluded from the analysis. Data analysis was performed over the shaded regions shown in Figure 8.18.

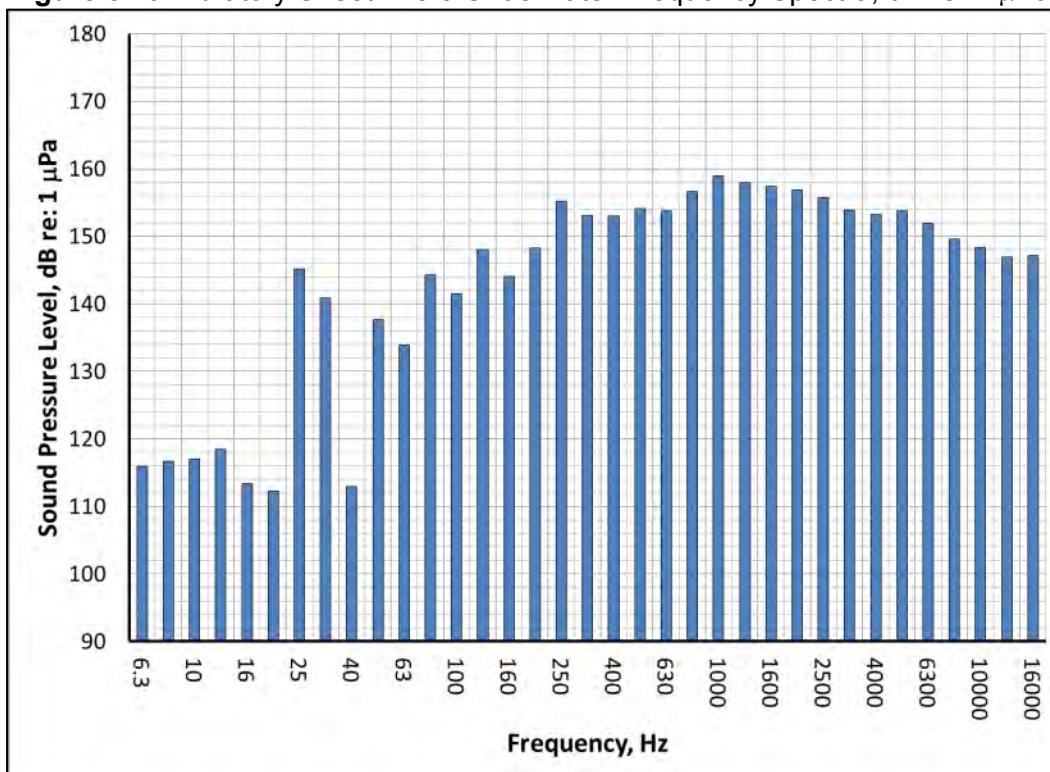
The underwater frequency spectrum associated with the highest measured 10-second RMS level during the drive of vibratory pile 3 is shown in Figure 8.19.

**Figure 8.18** Vibratory Sheet Pile 3 Peak Sound Pressure, Pa



Source: The Greenbusch Group, Inc.

**Figure 8.19** Vibratory Sheet Pile 3 Underwater Frequency Spectra, dB re: 1  $\mu$ Pa



Source: The Greenbusch Group, Inc.

### 8.3.2 Airborne Measurement Results

Airborne sound data gathered during the installation of the third unobstructed sheet pile driven with a vibratory hammer was analyzed to determine the range and average of 10-second RMS values between 10 Hz and 20 kHz while the vibratory hammer was operating at full power.

**Table 8.14** Vibratory Sheet Pile 3 Airborne Sound Levels, dB re: 20  $\mu$ Pa

Pile ID	Minimum	Maximum	Average
VIB-3	101	112	109

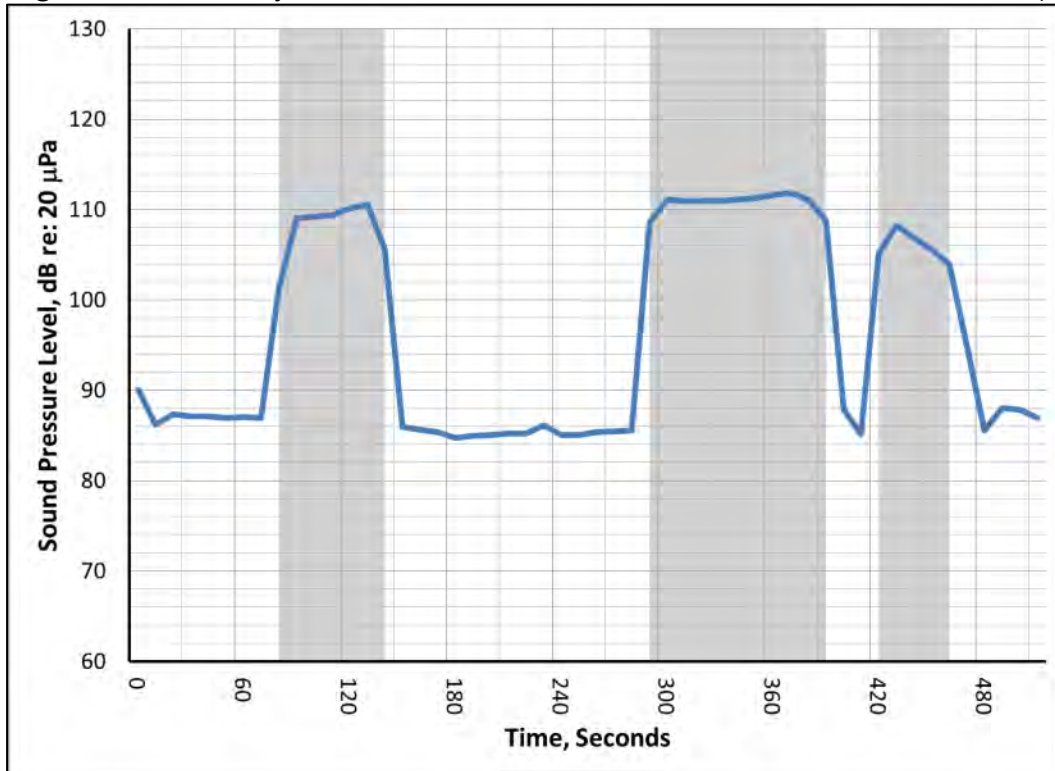
Source: The Greenbusch Group, Inc.

The results in Table 8.14 were produced by excluding periods when vibratory pile installation was not taking place under full power. The portions of the pile installation included in the analysis are represented by the shaded regions shown in Figure 8.20. Figure 8.20 also presents the 10-second RMS airborne sound levels measured over the entire drive of vibratory sheet pile 3.

Figure 8.21 provides the airborne frequency spectrum associated with the highest measured 10-second RMS level recorded during the drive of vibratory sheet pile 3.

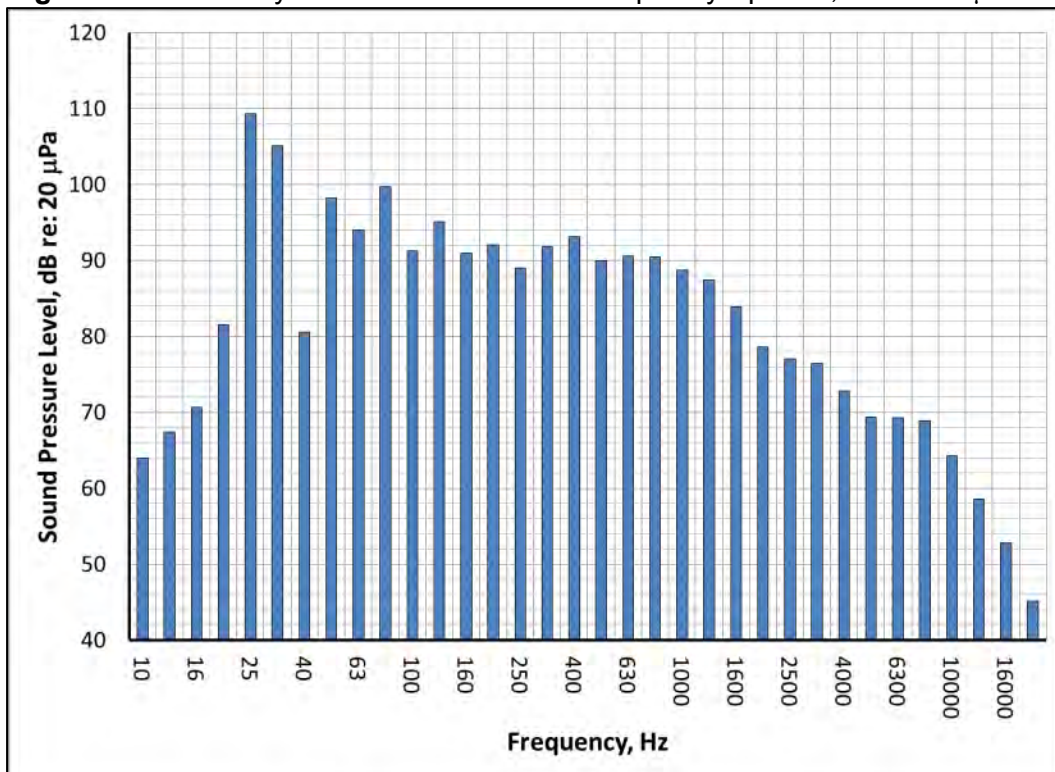


**Figure 8.20** Vibratory Sheet Pile 3 Airborne 10-Second RMS Values, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

**Figure 8.21** Vibratory Sheet Pile 3 Airborne Frequency Spectra, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.



#### 8.4 Vibratory Sheet Pile 4

The forth unobstructed steel sheet pile driven with a vibratory hammer was monitored on October 31, 2014. The drive started at 10:00 AM and did not include a ramp-up. Table 8.15 tabulates the distance between the pile and the water's edge, the water depth at the pile's location, depth into the substrate the pile was driven and the duration of the drive.

**Table 8.15** Vibratory Sheet Pile 4 Pile Information, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Drive Time (minutes)
VIB-4	10/31/14	None	3	20	40	12

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Logs

Airborne sound level measurements were made 50 feet from vibratory sheet pile 4 at an elevation of approximately 7 feet above the pier. Hydrophones were located 33 feet from the pile and maintained an unobstructed sound transmission path to the pile throughout the duration of the drive. Table 8.16 below provides information on the water depth at the location of the hydrophones, hydrophone depth, distance between the hydrophones and the distance between the hydrophones and the pile.

**Table 8.16** Vibratory Sheet Pile 4 Hydrophone Location Information, Feet

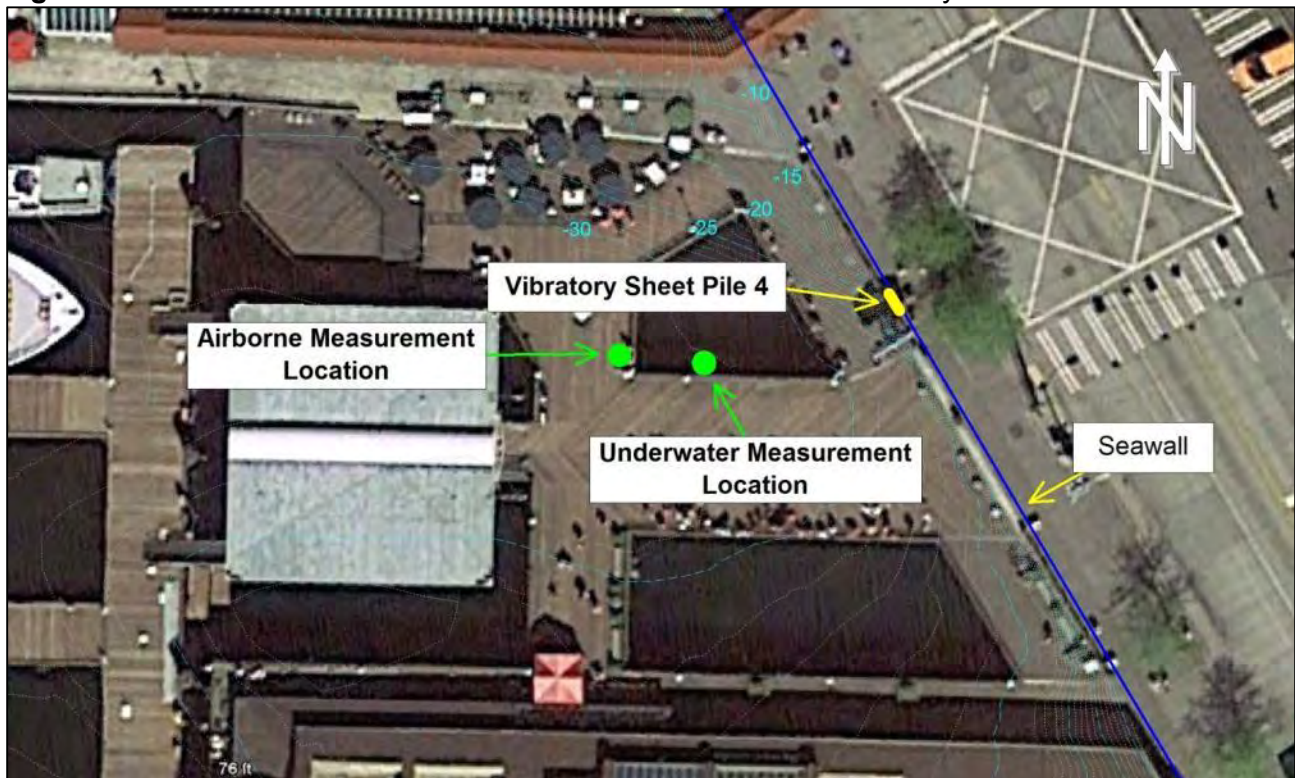
Pile ID	Depth at Measurement Location <sup>1</sup>	Hydrophone	Hydrophone Depth	Distance between Hydrophones	Distance to Pile
VIB-4	40	Upper	3	33	33
		Lower	36		

1. Depth at start of pile drive

Source: The Greenbusch Group, Inc. NOAA Station #9447130

Figure 8.22 illustrates the locations of vibratory sheet pile 4, hydrophones and airborne sound monitoring equipment. Photos showing vibratory sheet pile 4 and the hydrophone measurement location are provided in Figure 8.23 and Figure 8.24.

**Figure 8.22** Sheet Pile Location and Measurement Locations of Vibratory Sheet Pile 4



Source: The Greenbusch Group, Inc.

**Figure 8.23** Vibratory Sheet Pile 4



Source: The Greenbusch Group, Inc.

**Figure 8.24** Vibratory Sheet Pile 4 Hydrophone



Source: The Greenbusch Group, Inc.

#### 8.4.1 Underwater Measurement Results

Underwater noise data collected during the drive of vibratory sheet pile 4 was analyzed to determine the range, average and standard deviation of the peak, 10-second RMS and SEL values for each marine mammal functional hearing group during periods when the vibratory hammer was operating at full power.

**Table 8.17** Vibratory Sheet Pile 4 Underwater Sound Levels, dB re: 1  $\mu$ Pa

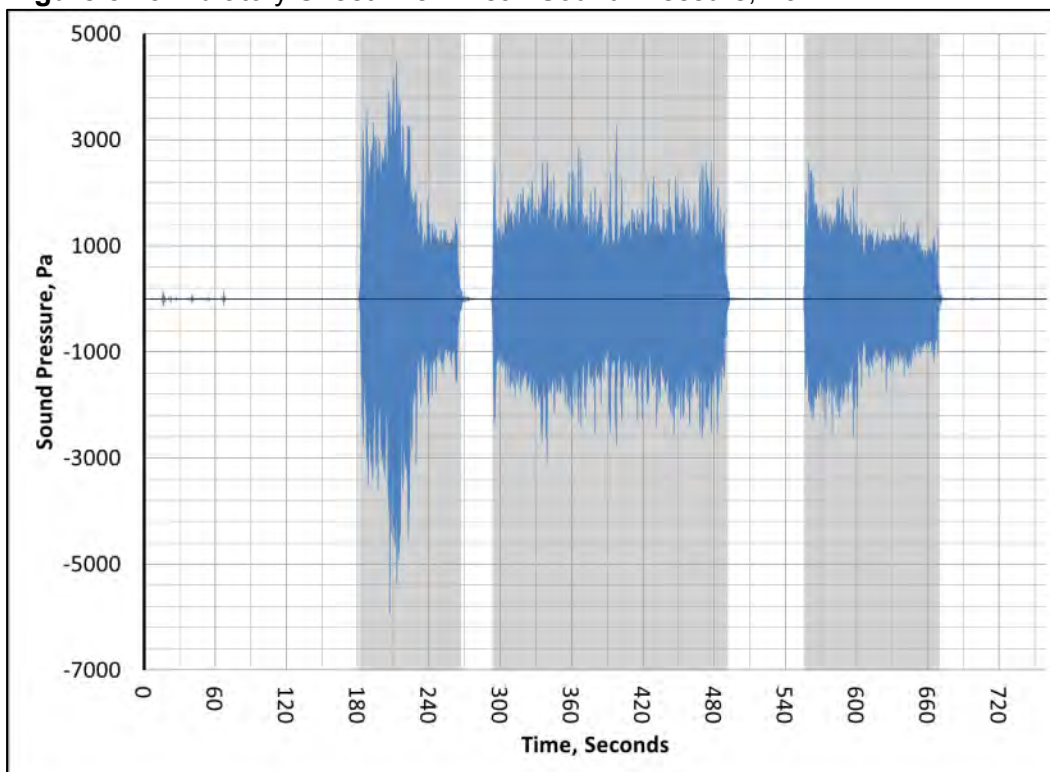
Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-4	7 Hz-20 kHz	180	195	3	<b>186</b>	163	174	2	<b>168</b>	146	175	3	<b>168</b>
	75 Hz-20 kHz	180	194	3	<b>186</b>	163	174	2	<b>168</b>	146	175	3	<b>168</b>
	150 Hz-20 kHz	181	193	3	<b>186</b>	163	174	2	<b>168</b>	146	175	3	<b>168</b>
	200 Hz-20 kHz	180	193	3	<b>186</b>	163	174	2	<b>168</b>	146	175	3	<b>168</b>

Source: The Greenbusch Group, Inc.

The hydroacoustic monitoring results provided in Table 8.17 were calculated by excluding periods when pile driving was not taking place under full power. Periods when data analysis was conducted are represented by the shaded regions in Figure 8.25.

The underwater frequency spectrum associated with the highest measured 10-second RMS level during the installation of vibratory pile 4 is shown in Figure 8.26 below.

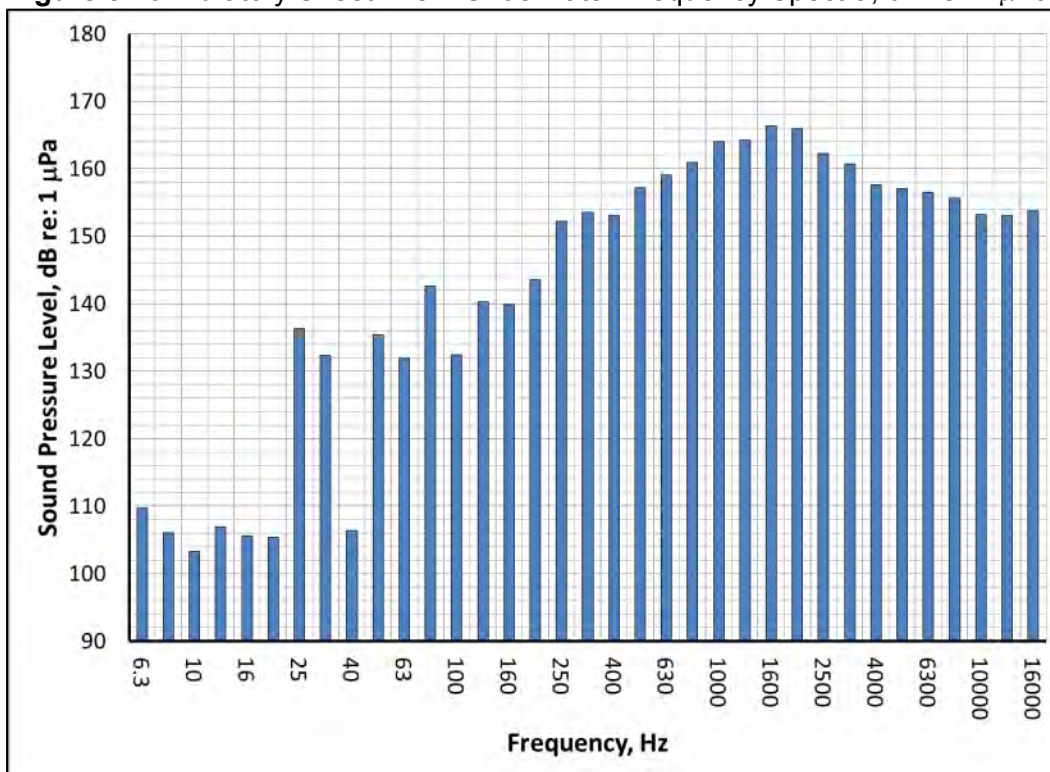
**Figure 8.25** Vibratory Sheet Pile 4 Peak Sound Pressure, Pa



Source: The Greenbusch Group, Inc.



**Figure 8.26** Vibratory Sheet Pile 4 Underwater Frequency Spectra, dB re: 1  $\mu$ Pa



Source: The Greenbusch Group, Inc.

#### 8.4.2 Airborne Measurement Results

Airborne sound level measurements made during the full power installation of vibratory sheet pile 4 were analyzed to determine the range and average of 10-second RMS values calculated using data between 10 Hz and 20 kHz.

**Table 8.18** Vibratory Sheet Pile 4 Airborne Sound Levels, dB re: 20  $\mu$ Pa

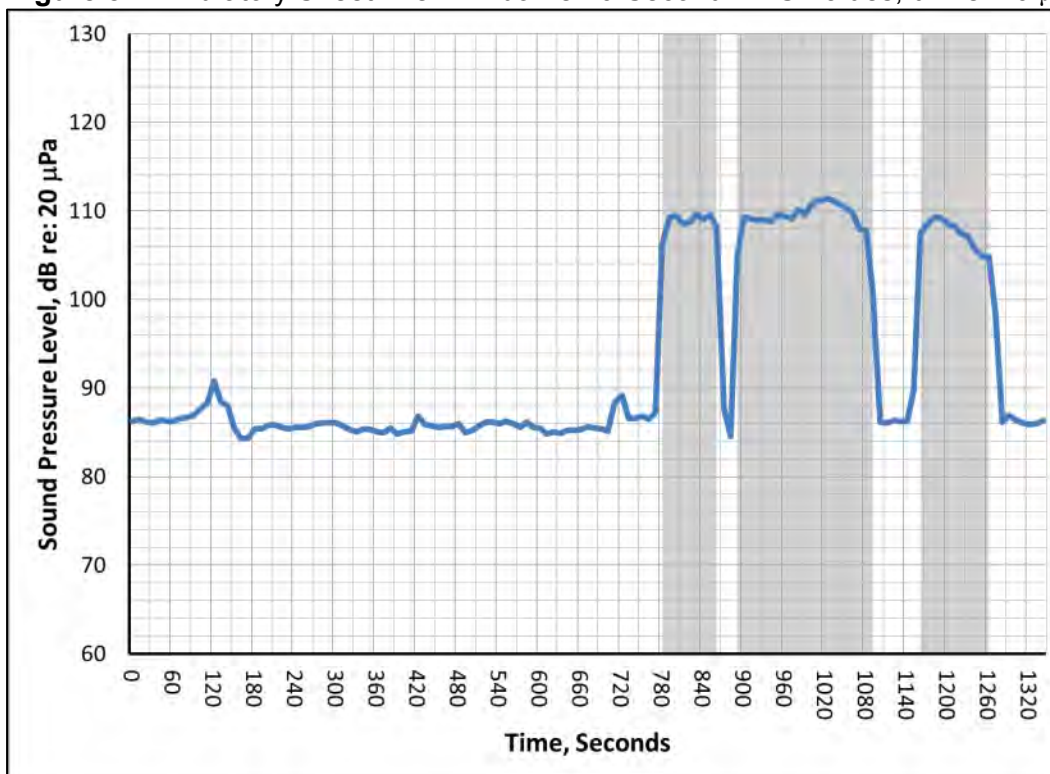
Pile ID	Minimum	Maximum	Average
VIB-4	101	111	109

Source: The Greenbusch Group, Inc.

The results in Table 8.18 were generated by only analyzing periods when the vibratory hammer was operating at full power. The portions of the pile drive included in this analysis are represented by the shaded regions in Figure 8.27. Figure 8.27 also shows the 10-second RMS airborne sound levels measured over the duration of the pile drive.

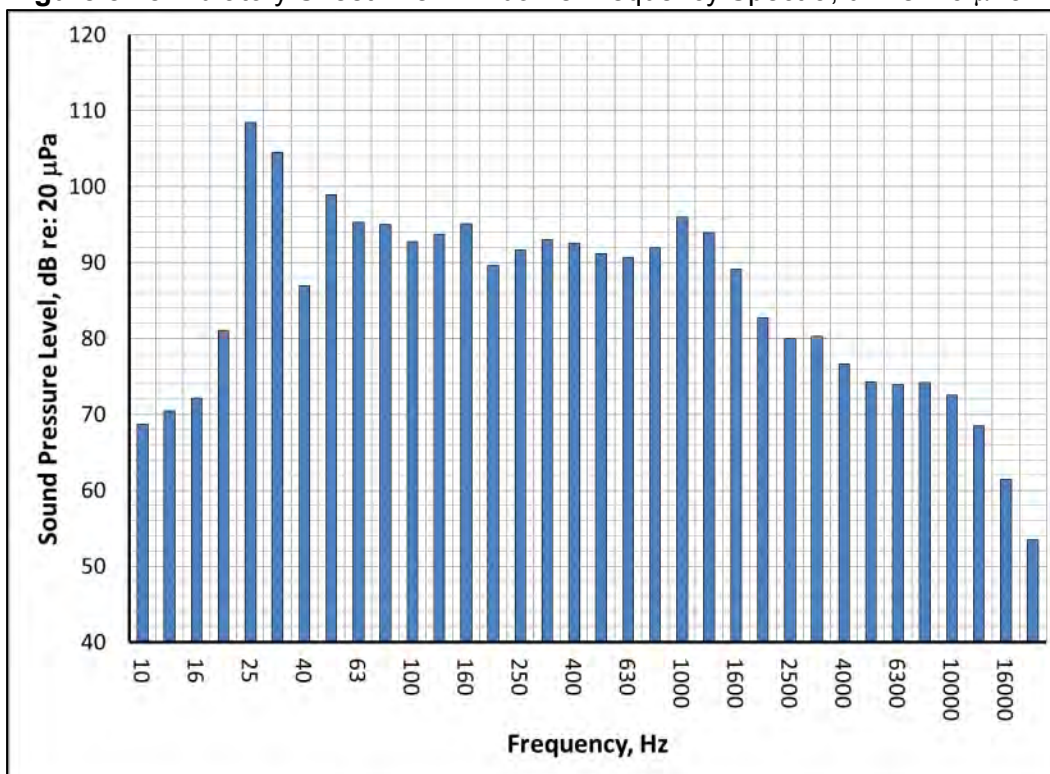
Figure 8.28 provides the airborne frequency spectrum associated with the highest measured 10-second RMS level measured during the drive of vibratory sheet pile 4.

**Figure 8.27** Vibratory Sheet Pile 4 Airborne 10-Second RMS Values, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

**Figure 8.28** Vibratory Sheet Pile 4 Airborne Frequency Spectra, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.



## 8.5 Vibratory Sheet Pile 5

Airborne and underwater sound generated by the fifth unobstructed steel sheet pile driven with a vibratory hammer was measured on November 7, 2014. The drive began at 11:20 AM and did not include a ramp-up. After approximately 25 minutes of pile driving, at approximately 11:45 AM pile driving was suspended. Pile driving resumed at approximately 12:35 PM and continued until the pile drive was complete. Table 8.19 provides the distance between the pile and the water's edge, water depth at the pile location, depth into the substrate the pile was driven and the duration of the pile drive.

**Table 8.19** Vibratory Sheet Pile 5 Pile Information, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Drive Time (minutes)
VIB-5	11/7/14	None	3	16	44	30

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Logs

Airborne sound level measurements were conducted 50 feet from vibratory sheet pile 5 at an elevation of approximately 7 feet above the pier. Hydrophones were located 34 feet from the pile with an unobstructed sound transmission path between the hydrophones and the pile. Table 8.20 presents the water depth at the hydrophones location, hydrophone depth, distance between hydrophones and the distance from the hydrophones to the pile.

**Table 8.20** Vibratory Sheet Pile 5 Hydrophone Location Information, Feet

Pile ID	Depth at Measurement Location <sup>1</sup>	Hydrophone	Hydrophone Depth	Distance between Hydrophones	Distance to Pile
VIB-5	28	Upper	3	22	34
		Lower	25		

1. Depth at start of pile drive

Source: The Greenbusch Group, Inc. NOAA Station #9447130

The locations of vibratory sheet pile 5, the hydrophones and airborne sound monitoring equipment are illustrated in Figure 8.29. Photos showing vibratory sheet pile 5 and the hydrophone measurement location are provided in Figure 8.30 and Figure 8.31.

**Figure 8.29** Sheet Pile Location and Measurement Locations of Vibratory Sheet Pile 5



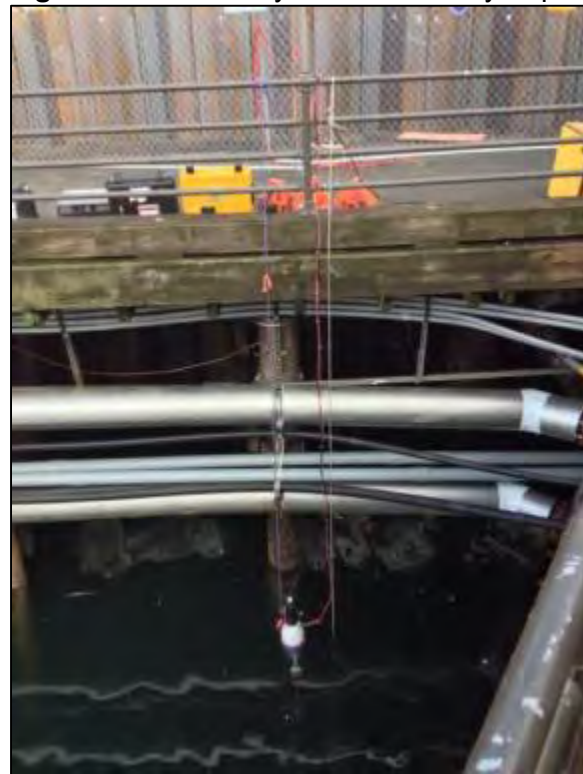
Source: The Greenbusch Group, Inc.

**Figure 8.30** Vibratory Sheet Pile 5



Source: The Greenbusch Group, Inc.

**Figure 8.31** Vibratory Sheet Pile 5 Hydrophone



Source: The Greenbusch Group, Inc.

### 8.5.1 Underwater Measurement Results

Hydroacoustic data collected during the drive of the fifth unobstructed steel sheet pile driven by a vibratory hammer was analyzed to determine the range, average and standard deviation of the peak, 10-second RMS and SEL values for each marine mammal functional hearing group during times when the vibratory hammer was operating under full power.

**Table 8.21** Vibratory Sheet Pile 5 Underwater Sound Levels, dB re: 1  $\mu$ Pa

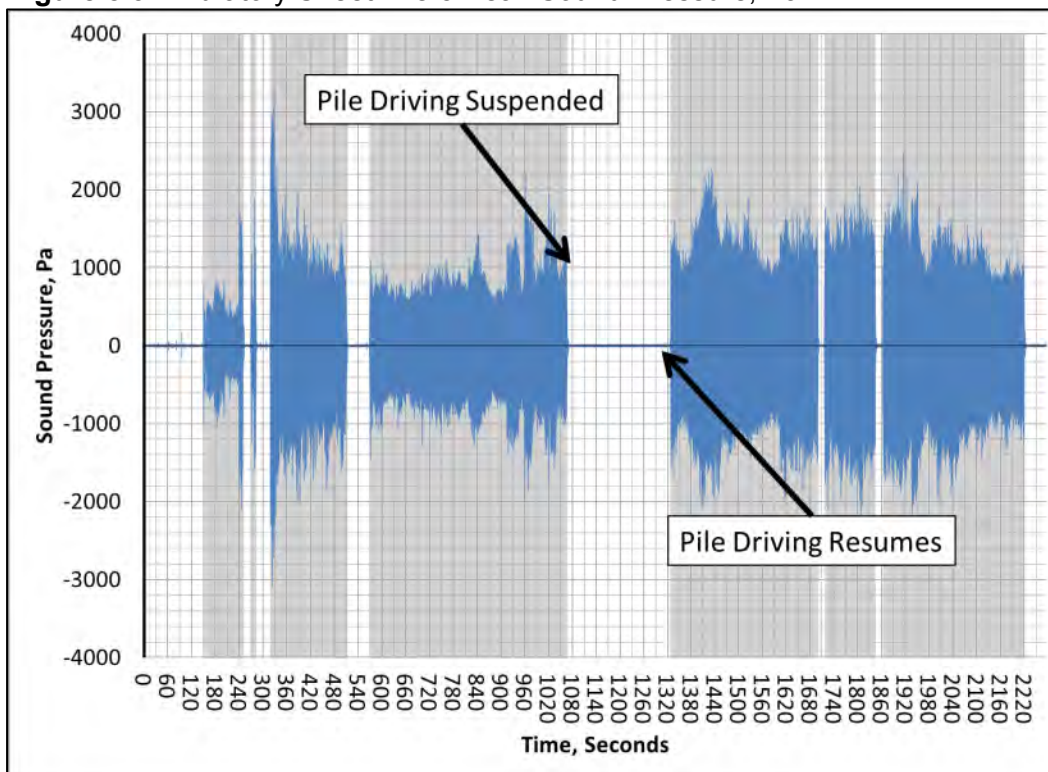
Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-5	7 Hz-20 kHz	166	190	3	<b>183</b>	142	171	3	<b>167</b>	149	172	3	<b>167</b>
	75 Hz-20 kHz	167	190	3	<b>183</b>	142	171	4	<b>167</b>	149	172	3	<b>167</b>
	150 Hz-20 kHz	167	190	3	<b>183</b>	142	171	3	<b>167</b>	149	172	3	<b>167</b>
	200 Hz-20 kHz	167	190	3	<b>183</b>	142	171	3	<b>167</b>	148	172	3	<b>167</b>

Source: The Greenbusch Group, Inc.

The hydroacoustic monitoring results presented in Table 8.21 were calculated by analyzing periods when the vibratory hammer was operating at full power. Times when the hammer was not operating were excluded from the analysis. The shaded regions of Figure 8.32 represent periods when the analysis was conducted.

The underwater frequency spectrum associated with the highest 10-second RMS level measured during the drive of vibratory sheet pile 5 is presented in Figure 8.33.

**Figure 8.32** Vibratory Sheet Pile 5 Peak Sound Pressure, Pa

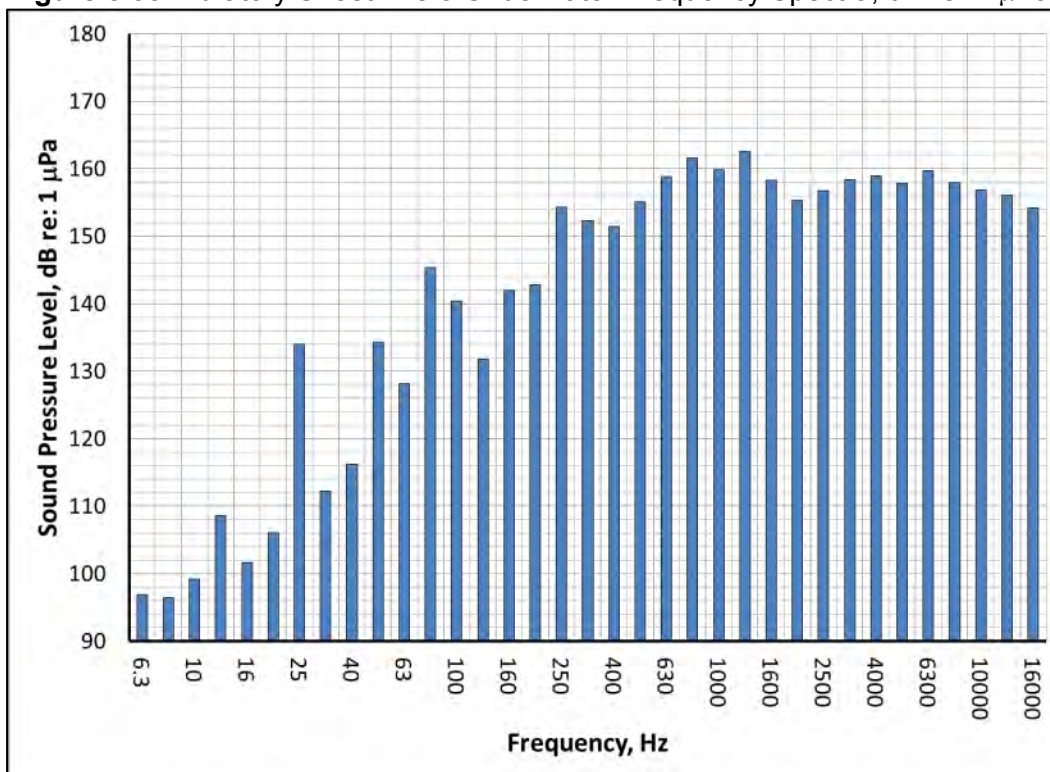


Note: Data collected between suspension of pile driving and the pile driving resuming is not shown.

Source: The Greenbusch Group, Inc.



**Figure 8.33** Vibratory Sheet Pile 5 Underwater Frequency Spectra, dB re: 1  $\mu$ Pa



Source: The Greenbusch Group, Inc.

### 8.5.2 Airborne Measurement Results

Airborne measurements conducted of sound generated by installation of vibratory sheet pile 5 during periods when the vibratory hammer was operating under full power were used to determine the range and average 10-second RMS values using data between 12.5 Hz and 16 kHz. As a result of the damage sustained to the laptop on October 31, 2014, the airborne measurement equipment was repurposed to collect hydroacoustic data. The Rion NL-32 was used to collect airborne spectral sound data and was only capable of measuring between 12.5 Hz and 16 kHz. Due to the time sensitive nature of the hydroacoustic monitoring (first 5 unobstructed piles require monitoring) there was insufficient time to rent additional equipment capable of measuring the full 10 Hz to 20 kHz frequency range.

**Table 8.22** Vibratory Sheet Pile 5 Airborne Sound Levels, dB re: 20  $\mu$ Pa

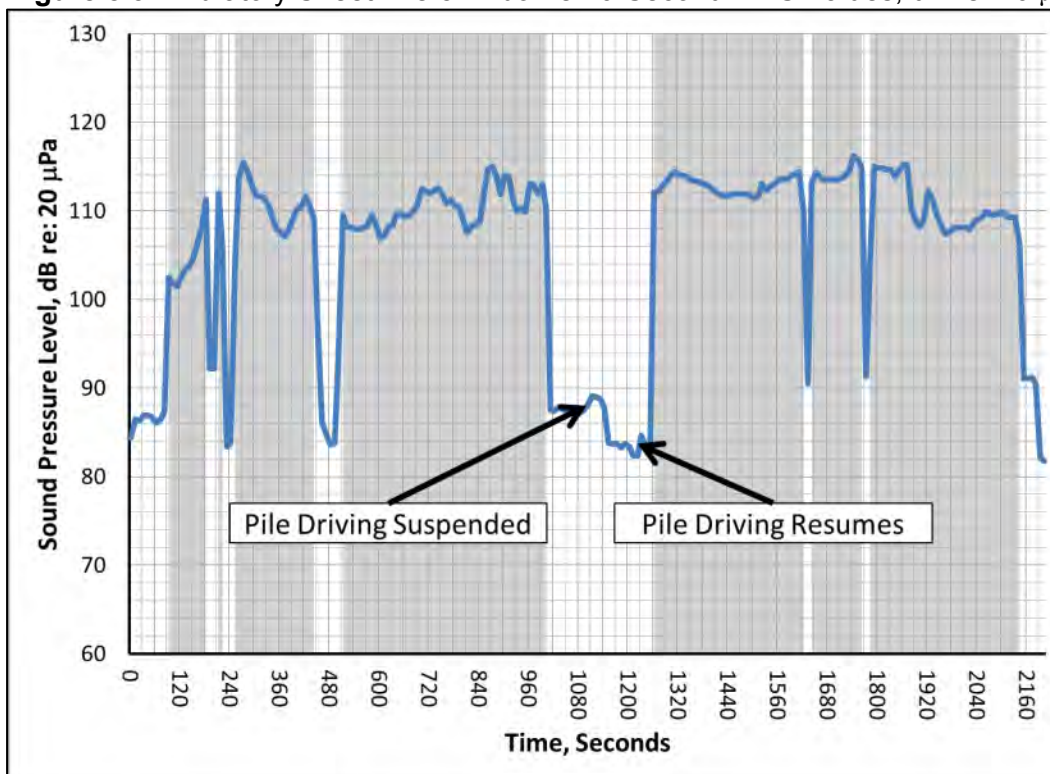
Pile ID	Minimum	Maximum	Average
VIB-5	102	116	111

Source: The Greenbusch Group, Inc.

The sound levels provided in Table 8.22 were calculated over periods of the drive when the vibratory hammer was operating under full power. The portions of the pile drive included in the analysis of airborne sound levels are represented by the shaded regions of Figure 8.34. Figure 8.34 also provides the 10-second RMS values measured over the duration of the pile drive.

Figure 8.35 presents a representative airborne frequency spectrum produced during the installation of vibratory sheet pile 5 under full power.

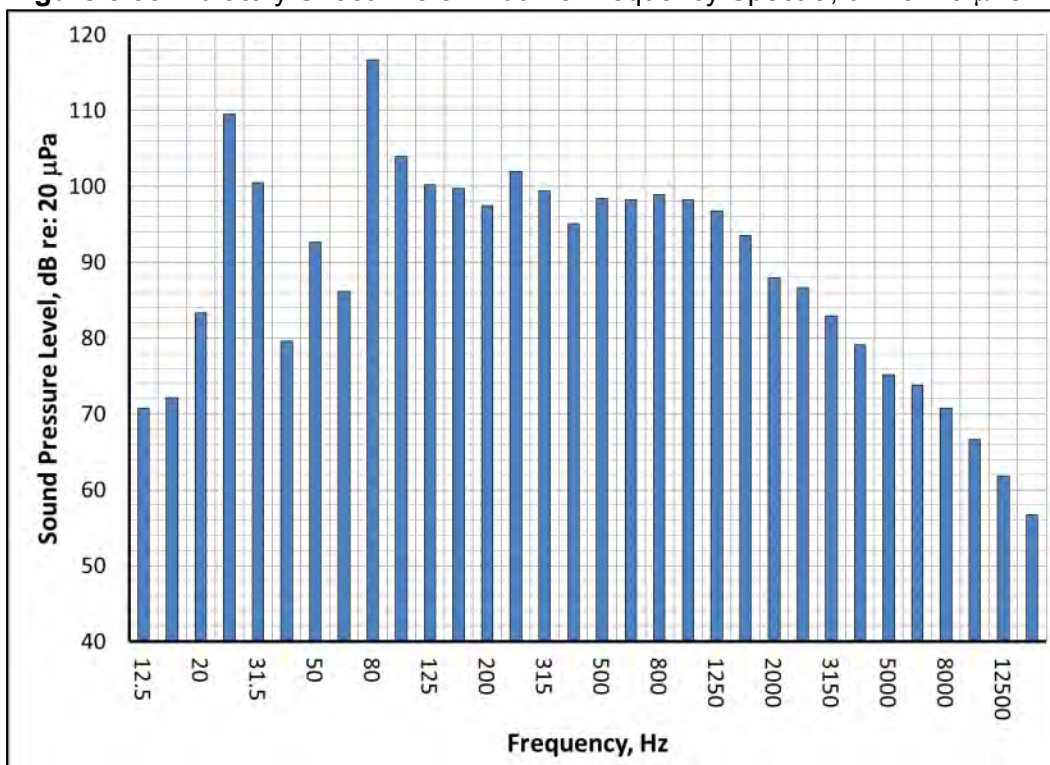
**Figure 8.34** Vibratory Sheet Pile 5 Airborne 10-Second RMS Values, dB re: 20  $\mu$ Pa



Note: Data collected between suspension of pile driving and the pile driving resuming is not shown.

Source: The Greenbusch Group, Inc.

**Figure 8.35** Vibratory Sheet Pile 5 Airborne Frequency Spectra, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.



## 9.0 IMPACT SHEET PILES ANALYSIS AND RESULTS

Airborne and underwater sound data was collected on November 7, 2014 and November 8, 2014 to assess sound levels generated by the first five unobstructed steel sheet piles driven with an impact hammer as required by the Project's ESA and MMPA consultation.

Airborne sound levels were measured using two sound level analyzers, the Rion NL-52 and the Rion NL-32. The Rion NL-52 collected continuous 10-second broadband RMS levels as well as 100 millisecond broadband RMS data. Airborne spectral data was collected using the Rion NL-32 sound level analyzer. Spectral measurements were made over multiple 10-second periods throughout each pile drive. These spectral measurements determined the maximum sound level in each 1/3 octave band ( $L_{max}$ ).

Hydroacoustic data collected during the impact driving of steel sheet piles were analyzed to determine the range, average and standard deviation of peak,  $RMS_{90}$ , and SEL values as well as the cSEL for each marine mammal functional hearing group as required by the ESA and MMPA. Periods when pile driving was not occurring under full power were excluded from this analysis. Ramp-up procedures were used at the start of each day and after breaks of more than one hour. However, only one of the monitored impact piles, impact sheet pile 1, met these timing requirements. Ramp-up activities were separated from the full power pile driving analysis and are presented separately.

Reported maximum and minimum values are either the maximum or minimum value from either of the two hydrophones. Standard deviation was calculated using the decibel values. The average sound levels were calculated using the mean sound pressure from each hydrophone, converted to decibels and taking the logarithmic average of the two values.

Data analysis was conducted for each marine mammal functional hearing group by applying a band pass filter to remove frequencies from the signal that are not included in the functional hearing group being analyzed. This filter provides a roll off of more than -40 dB per decade.

The  $RMS_{90}$  energy was established between the 5<sup>th</sup> percentile and 95<sup>th</sup> percentile of each recorded pile strike. Figures illustrating the portion of the pile strike containing 90% of the acoustic energy for the strike that generated the highest peak sound pressure level for each monitored pile are presented in the sections that follow.

SEL values for impact pile driving of steel sheet piles were calculated for each pile strike over the duration of the strike containing 90% of the acoustic energy using the following formula:

$$SEL = RMS(dB) + 10 \log_{10}(\tau)$$

Where  $\tau$  is the time interval containing 90% of the acoustic energy in each pile strike.

cSEL values were calculated using the SEL value corresponding to the maximum peak pile strike using the following formula, which is required by the ESA documents:

$$cSEL = SEL_{single} + 10 \log_{10}(n)$$

Where  $SEL_{single}$  is the SEL value corresponding to the pile strike which produced the highest peak sound pressure and  $n$  is the total number of pile strikes included in the analysis.

A summary of underwater sound levels produced during the impact pile driving of the first five unobstructed steel sheet piles is provided in Table 9.1. A detailed description of each sheet pile monitored during impact pile driving is provided in the sections that follow.

**Table 9.1** Underwater Sound Levels from Impact Pile Driving, dB re: 1  $\mu$ Pa

Pile ID	Frequency Range	Peak				RMS <sub>90</sub>				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-1	7 Hz-20 kHz	175	200	5	<b>192</b>	163	186	5	<b>180</b>	150	172	4	<b>166</b>	<b>190</b>
	75 Hz-20 kHz	175	200	5	<b>192</b>	162	186	5	<b>180</b>	150	172	4	<b>166</b>	<b>190</b>
	150 Hz-20 kHz	175	200	5	<b>192</b>	162	186	5	<b>180</b>	150	172	4	<b>166</b>	<b>190</b>
	200 Hz-20 kHz	175	200	5	<b>192</b>	162	186	5	<b>180</b>	150	172	5	<b>166</b>	<b>190</b>
IMP-2	7 Hz-20 kHz	189	204	1	<b>198</b>	176	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>198</b>
	75 Hz-20 kHz	189	203	1	<b>198</b>	175	189	1	<b>185</b>	164	173	1	<b>170</b>	<b>198</b>
	150 Hz-20 kHz	189	203	1	<b>198</b>	175	189	1	<b>185</b>	162	173	1	<b>169</b>	<b>198</b>
	200 Hz-20 kHz	189	203	1	<b>198</b>	173	189	1	<b>185</b>	162	173	1	<b>169</b>	<b>198</b>
IMP-3	7 Hz-20 kHz	189	204	2	<b>198</b>	174	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>202</b>
	75 Hz-20 kHz	189	204	2	<b>198</b>	174	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>202</b>
	150 Hz-20 kHz	189	204	2	<b>198</b>	174	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>202</b>
	200 Hz-20 kHz	189	204	2	<b>198</b>	174	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>202</b>
IMP-4	7 Hz-20 kHz	191	202	1	<b>197</b>	178	187	1	<b>184</b>	165	172	1	<b>169</b>	<b>199</b>
	75 Hz-20 kHz	191	202	1	<b>197</b>	179	187	1	<b>184</b>	164	172	1	<b>169</b>	<b>198</b>
	150 Hz-20 kHz	192	202	1	<b>197</b>	179	187	1	<b>184</b>	164	172	1	<b>169</b>	<b>198</b>
	200 Hz-20 kHz	192	202	1	<b>197</b>	179	187	1	<b>184</b>	164	172	1	<b>169</b>	<b>198</b>
IMP-5	7 Hz-20 kHz	190	204	1	<b>197</b>	177	188	1	<b>184</b>	163	173	1	<b>170</b>	<b>201</b>
	75 Hz-20 kHz	190	203	1	<b>197</b>	177	188	1	<b>184</b>	165	173	1	<b>170</b>	<b>201</b>
	150 Hz-20 kHz	191	202	1	<b>197</b>	177	188	1	<b>184</b>	163	173	1	<b>170</b>	<b>201</b>
	200 Hz-20 kHz	190	203	1	<b>197</b>	177	188	1	<b>184</b>	163	173	1	<b>170</b>	<b>201</b>

Source: The Greenbusch Group, Inc.

A summary of airborne sound levels produced by the impact pile driving of steel sheet piles is provided in Table 9.2.

**Table 9.2** Airborne Sound Levels from Impact Pile Driving, dB re: 20  $\mu$ Pa

Pile ID	Minimum	Maximum	Average
IMP-1	101	118	<b>109</b>
IMP-2	113	119	<b>116</b>
IMP-3	112	122	<b>116</b>
IMP-4	111	119	<b>114</b>
IMP-5	112	118	<b>115</b>

Source: The Greenbusch Group, Inc.

## 9.1 Impact Sheet Pile 1

The first unobstructed steel sheet pile requiring an impact hammer was monitored on November 7, 2014. The drive began at 7:40 AM and included a ramp-up per the Project's ESA and MMPA requirements. After the ramp-up, full power pile driving began. Table 9.3 tabulates the distance from the pile to the water's edge, water depth at the pile location, depth into the substrate the pile was driven and the number of pile strikes used in the analysis.

**Table 9.3** Impact Sheet Pile 1 Information, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Number of Strikes (ramp-up/full power) <sup>1</sup>
IMP-1	11/7/14	None	3	20	40	3/69

1. Number of strikes analyzed. This number differs from the number of strikes reported in the pile logs because only pile strikes under full power were analyzed.

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Driving Logs

Airborne sound levels were measured 50 feet from the sheet pile at an elevation of approximately 7 feet above the pier. Hydrophones were located 32 feet from the pile and an unobstructed acoustical path to the pile was maintained throughout the duration of the pile drive. Table 9.4 below presents the water depth at the hydrophone location, depth of each hydrophone and the distance between the hydrophones as well as the distance between the hydrophones and the sheet pile.

**Table 9.4** Impact Sheet Pile 1 Hydrophone Location Information, Feet

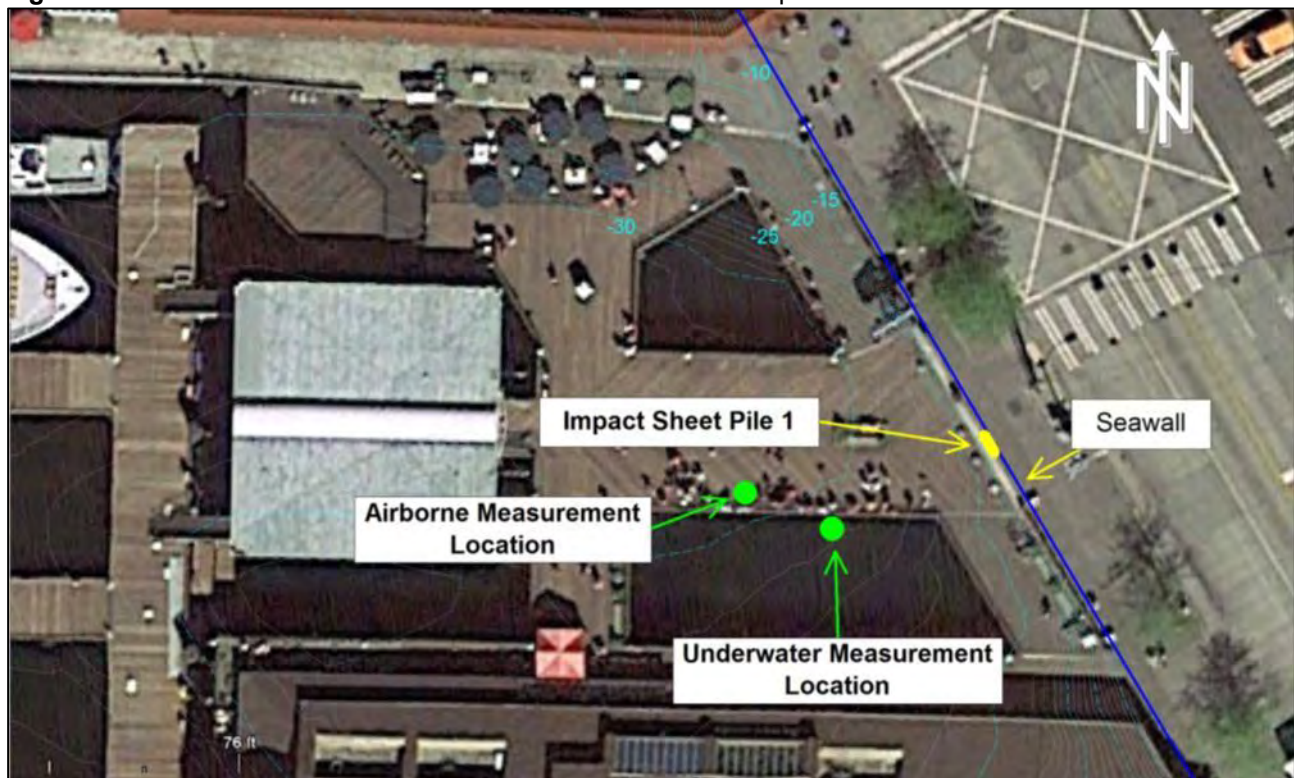
Pile ID	Depth at Measurement Location <sup>1</sup>	Hydrophone	Hydrophone Depth	Distance between Hydrophones	Distance to Pile
IMP-1	32	Upper	3	25	32
		Lower	28		

1. Depth at start of pile drive

Source: The Greenbusch Group, Inc. NOAA Station #9447130

The locations of the first sheet pile requiring an impact hammer, hydrophones and airborne sound monitoring equipment are provided in Figure 9.1. Photos of impact sheet pile 1 and the hydrophone location are provided in Figure 9.2 and Figure 9.3.

**Figure 9.1** Sheet Pile Location and Measurement Locations of Impact Sheet Pile 1



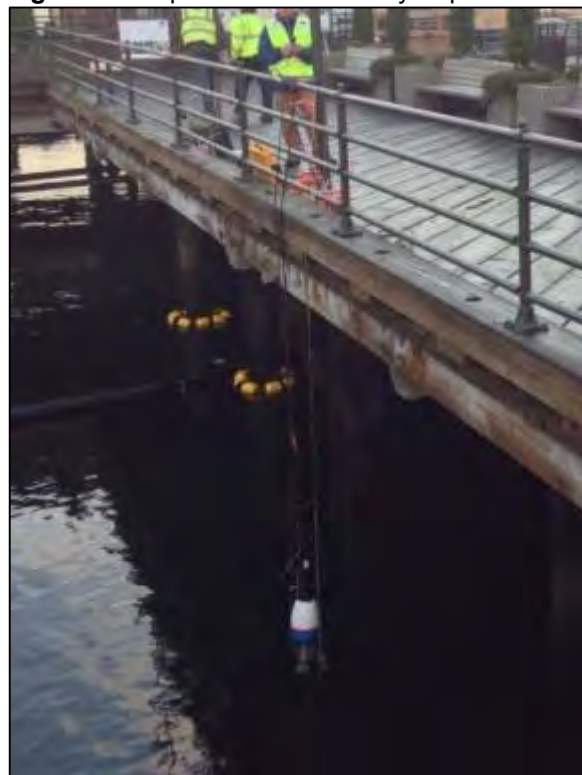
Source: The Greenbusch Group, Inc.

**Figure 9.2** Impact Sheet Pile 1



Source: The Greenbusch Group, Inc.

**Figure 9.3** Impact Sheet Pile 1 Hydrophone



Source: The Greenbusch Group, Inc.

### 9.1.1 Underwater Measurement Results

Underwater sound data gathered during installation of the first unobstructed steel sheet pile was analyzed to determine the range, average and standard deviation of peak, RMS<sub>90</sub> and SEL values as well as to calculate the cSEL for each marine mammal functional hearing group during the ramp-up and full power pile driving. The results of this hydroacoustic analysis are provided in Table 9.5.

**Table 9.5** Impact Sheet Pile 1 Underwater Sound Levels, dB re: 1 µPa

Pile ID	Frequency Range	Peak				RMS <sub>90</sub>				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-1	Ramp-Up													
	7 Hz-20 kHz	176	189	4	184	162	174	5	170	152	162	4	159	167
	75 Hz-20 kHz	177	189	3	184	162	174	5	170	158	162	3	159	167
	150 Hz-20 kHz	176	189	4	184	162	174	5	170	152	162	4	159	167
	200 Hz-20 kHz	176	189	4	184	161	174	5	170	152	162	4	159	167
	Full Power													
	7 Hz-20 kHz	175	200	5	192	163	186	5	180	150	172	4	166	190
	75 Hz-20 kHz	175	200	5	192	162	186	5	180	150	172	4	166	190
	150 Hz-20 kHz	175	200	5	192	162	186	5	180	150	172	4	166	190
	200 Hz-20 kHz	175	200	5	192	162	186	5	180	150	172	5	166	190

Source: The Greenbusch Group, Inc.

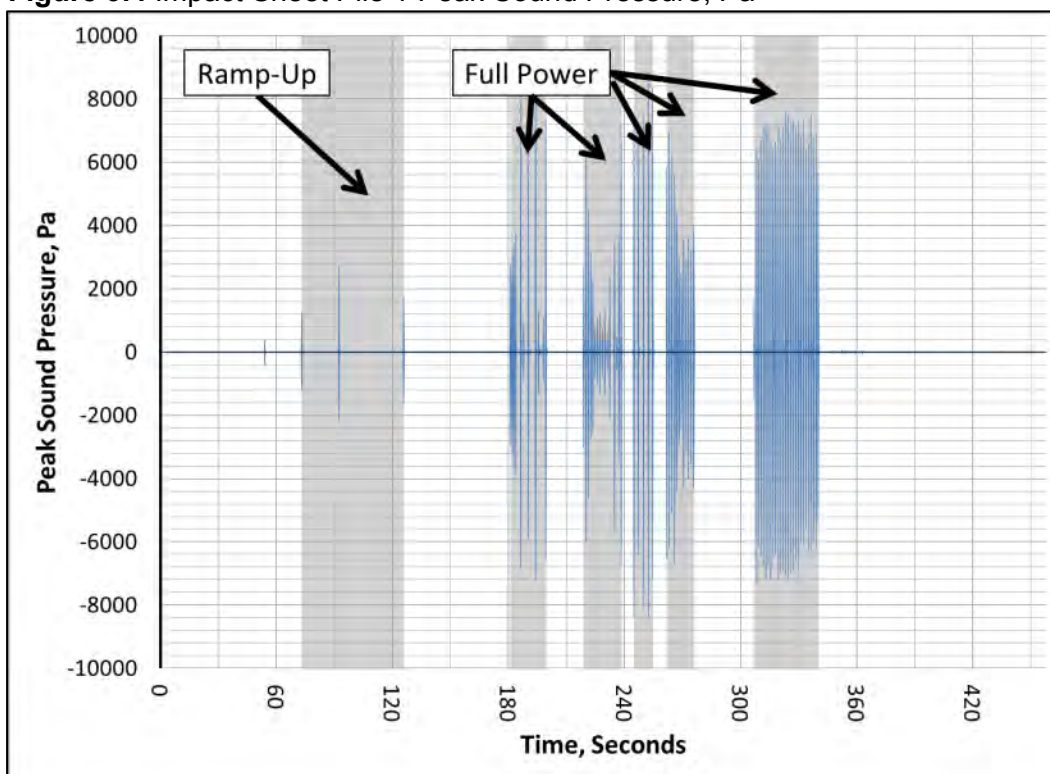
The results shown in Table 9.5 above were calculated by analyzing sound levels generated by pile driving activities taking place under full power as well as during ramp-up. Periods when the impact hammer was not operating at full power as well as periods between pile strikes were excluded from the analysis. The shaded regions of Figure 9.4 indicate periods included in the analysis.

The underwater frequency spectrum associated with the highest peak sound level measured during the drive of impact sheet pile 1 is shown in Figure 9.5

The waveform generated by the pile strike that produced the highest peak sound pressure level is shown in Figure 9.6. The shaded region of Figure 9.6 illustrates the portion of the waveform containing 90% of the acoustical energy.

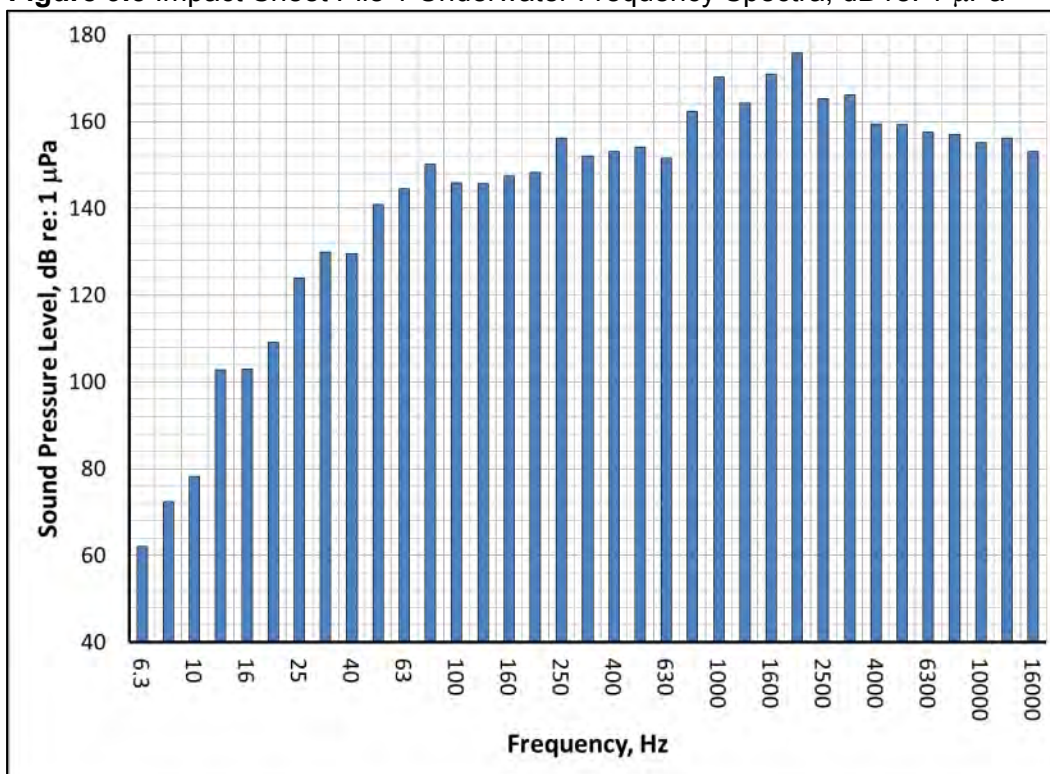


**Figure 9.4** Impact Sheet Pile 1 Peak Sound Pressure, Pa



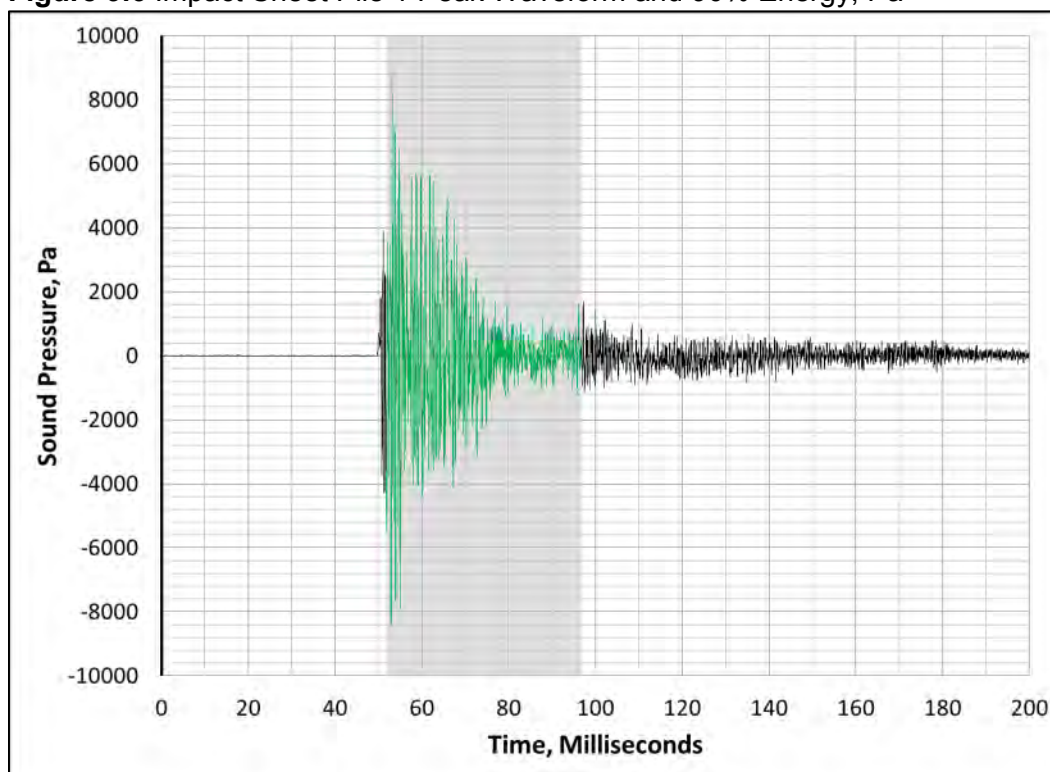
Source: The Greenbusch Group, Inc.

**Figure 9.5** Impact Sheet Pile 1 Underwater Frequency Spectra, dB re: 1  $\mu$ Pa



Source: The Greenbusch Group, Inc.

**Figure 9.6** Impact Sheet Pile 1 Peak Waveform and 90% Energy, Pa



Source: The Greenbusch Group, Inc.

### 9.1.2 Airborne Measurement Results

Measurements were conducted of airborne sound levels generated by the installation of the first sheet pile requiring an impact hammer. Data collected during these measurements was used to determine the range and average RMS sound levels produced while the pile was being driven under full power as well as during the ramp-up. 100 millisecond RMS data was used for the airborne analysis.

**Table 9.6** Impact Sheet Pile 1 Airborne Sound Levels, dB re: 20  $\mu$ Pa

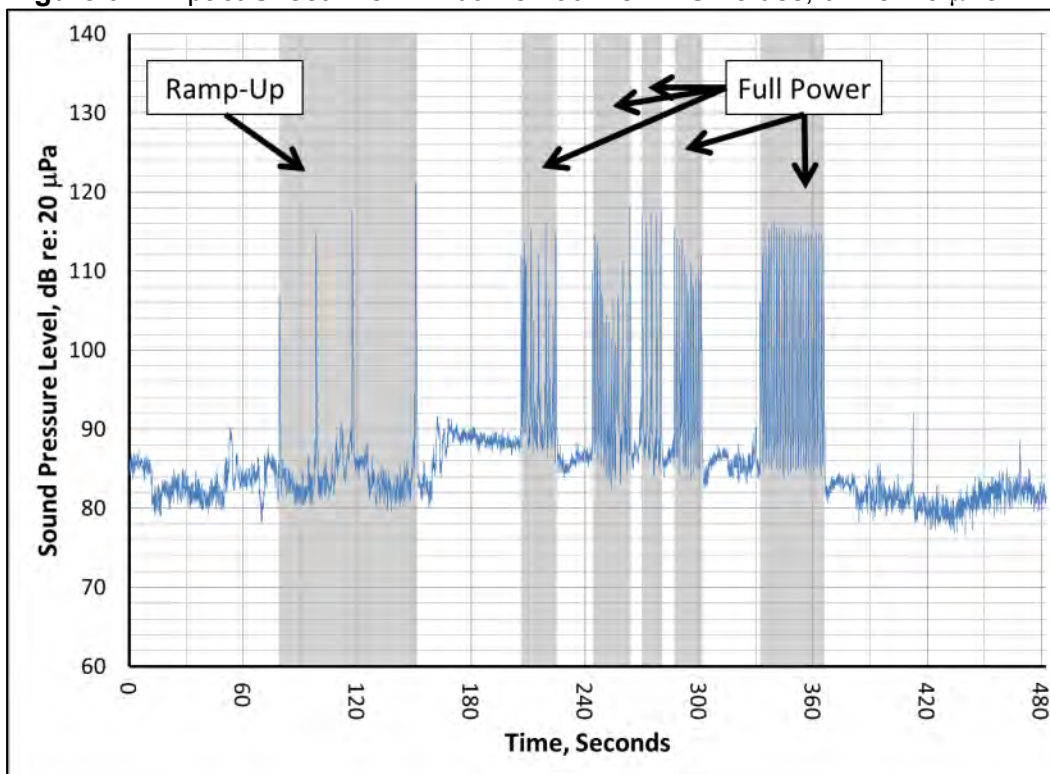
Pile ID	Minimum	Maximum	Average
IMP-1	<i>Ramp-Up</i>		
	102	121	<b>112</b>
	<i>Full Power</i>		
	101	118	<b>109</b>

Source: The Greenbusch Group, Inc.

The results presented in Table 9.6 were calculated over periods when the impact hammer was operating at full power, as well as during ramp-up. The portions of the pile driving included in the analysis of airborne sound levels are represented by the shaded portions of Figure 9.7. Figure 9.7 also provides the 100 millisecond RMS values recorded during over the duration of the pile drive.

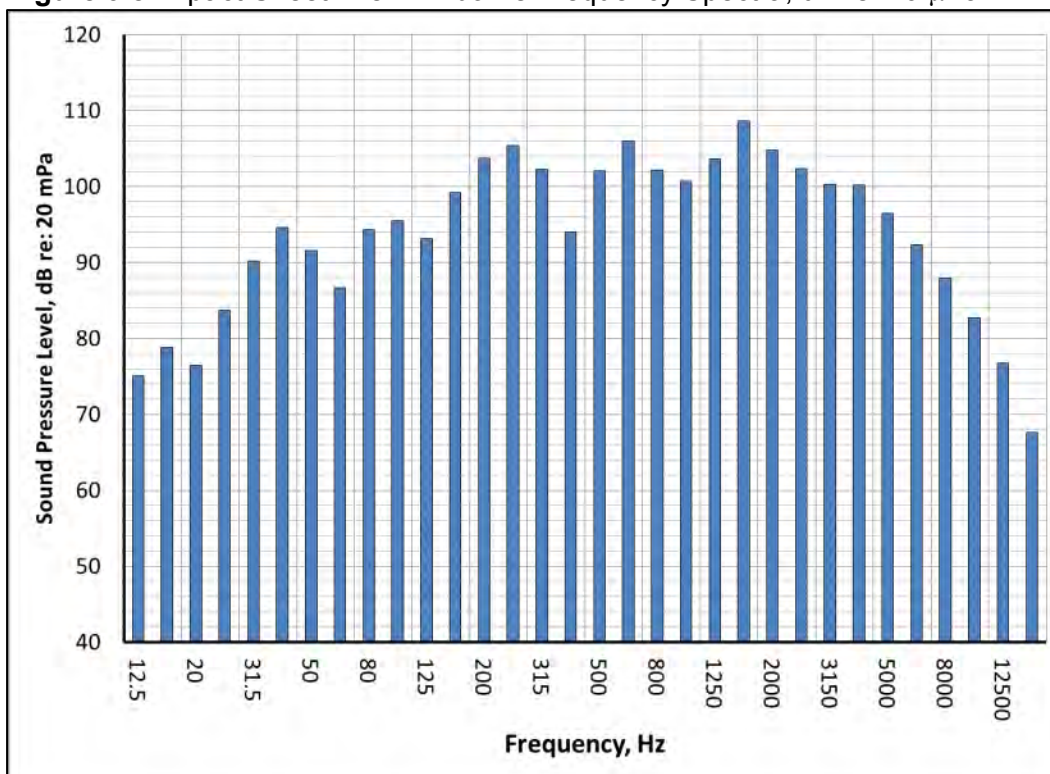
Figure 9.8 illustrates a representative airborne frequency spectrum generated during the full power drive of impact sheet pile 1.

**Figure 9.7** Impact Sheet Pile 1 Airborne 100-ms RMS Values, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

**Figure 9.8** Impact Sheet Pile 1 Airborne Frequency Spectra, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

## 9.2 Impact Sheet Pile 2

The second unobstructed steel sheet pile that required an impact hammer was monitored on November 8, 2014. Impact pile driving began at 9:45 AM and did not include a ramp up. During the impact pile driving, vibratory pile installation was occurring simultaneously to the south. Measured sound levels were dominated by the impact hammer and audio recordings were reviewed to verify that sound generated by the vibratory hammer did not influence the measurements of the impact hammer. Table 9.7 provides the distance from the pile to the water's edge, water depth at the pile location, depth into the substrate the pile was driven and the number of strikes used in the analysis.

**Table 9.7** Impact Sheet Pile 2 Information, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Number of Strikes <sup>1</sup>
IMP-2	11/8/14	None	3	20	40	446

1. Number of strikes analyzed. This number differs from the number of strikes reported in the pile logs because only pile strikes under full power were analyzed.

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Driving Logs

Airborne sound levels were monitored 50 feet from the sheet pile. The microphone was located approximately 7 feet above the pier. Hydrophones were located 33 feet from the sheet pile and maintained an unobstructed acoustical transmission path to the pile. Table 9.8 below provides the water depth at the location of the hydrophones, depth of each hydrophone, distance between the hydrophones and the distance between the hydrophones and the sheet pile.

**Table 9.8** Impact Sheet Pile 2 Hydrophone Location Information, Feet

Pile ID	Depth at Measurement Location <sup>1</sup>	Hydrophone	Hydrophone Depth	Distance between Hydrophones	Distance to Pile
IMP-2	33	Upper	3	27	33
		Lower	30		

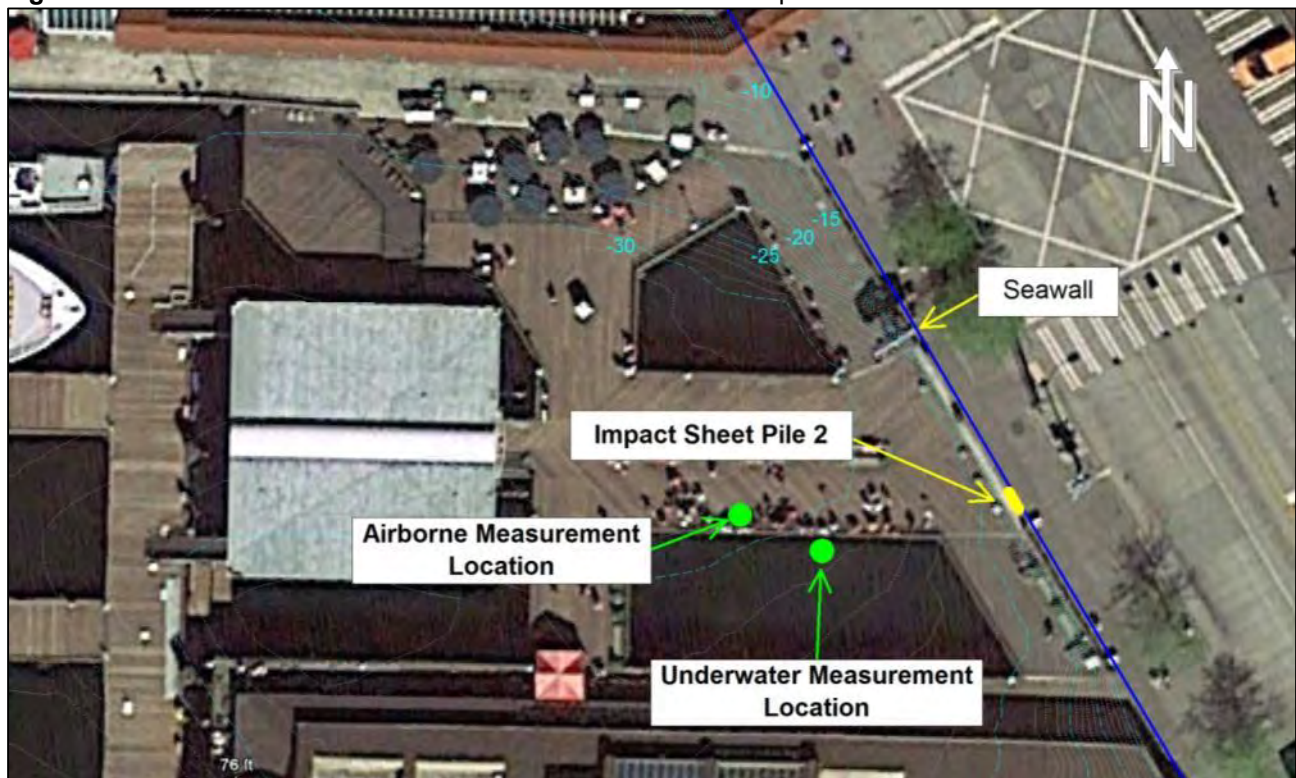
1. Depth at start of pile drive

Source: The Greenbusch Group, Inc. NOAA Station #9447130

The locations of the second sheet pile requiring an impact hammer, hydrophones and airborne sound monitoring equipment are provided in Figure 9.9. Photos of impact sheet pile 2 and the hydrophone measurement location are provided in Figure 9.10 and Figure 9.11.



**Figure 9.9** Sheet Pile Location and Measurement Locations of Impact Sheet Pile 2



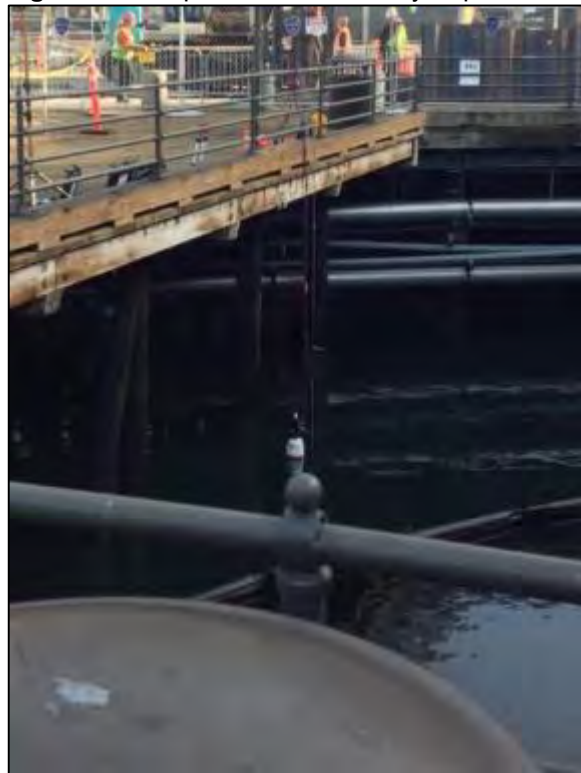
Source: The Greenbusch Group, Inc.

**Figure 9.10** Impact Sheet Pile 2



Source: The Greenbusch Group, Inc.

**Figure 9.11** Impact Sheet Pile 2 Hydrophone



Source: The Greenbusch Group, Inc.

### 9.2.1 Underwater Measurement Results

Hydroacoustic measurement data was collected during impact driving of the second unobstructed steel sheet pile. This data was analyzed to determine the range, average and standard deviation of peak, RMS<sub>90</sub> and SEL values as well as to calculate the cSEL for each marine mammal functional hearing group during times that the impact hammer was operating at full power.

**Table 9.9** Impact Sheet Pile 2 Underwater Sound Levels, dB re: 1  $\mu$ Pa

Pile ID	Frequency Range	Peak				RMS <sub>90</sub>				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-2	7 Hz-20 kHz	189	204	1	<b>198</b>	176	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>198</b>
	75 Hz-20 kHz	189	203	1	<b>198</b>	175	189	1	<b>185</b>	164	173	1	<b>170</b>	<b>198</b>
	150 Hz-20 kHz	189	203	1	<b>198</b>	175	189	1	<b>185</b>	162	173	1	<b>169</b>	<b>198</b>
	200 Hz-20 kHz	189	203	1	<b>198</b>	173	189	1	<b>185</b>	162	173	1	<b>169</b>	<b>198</b>

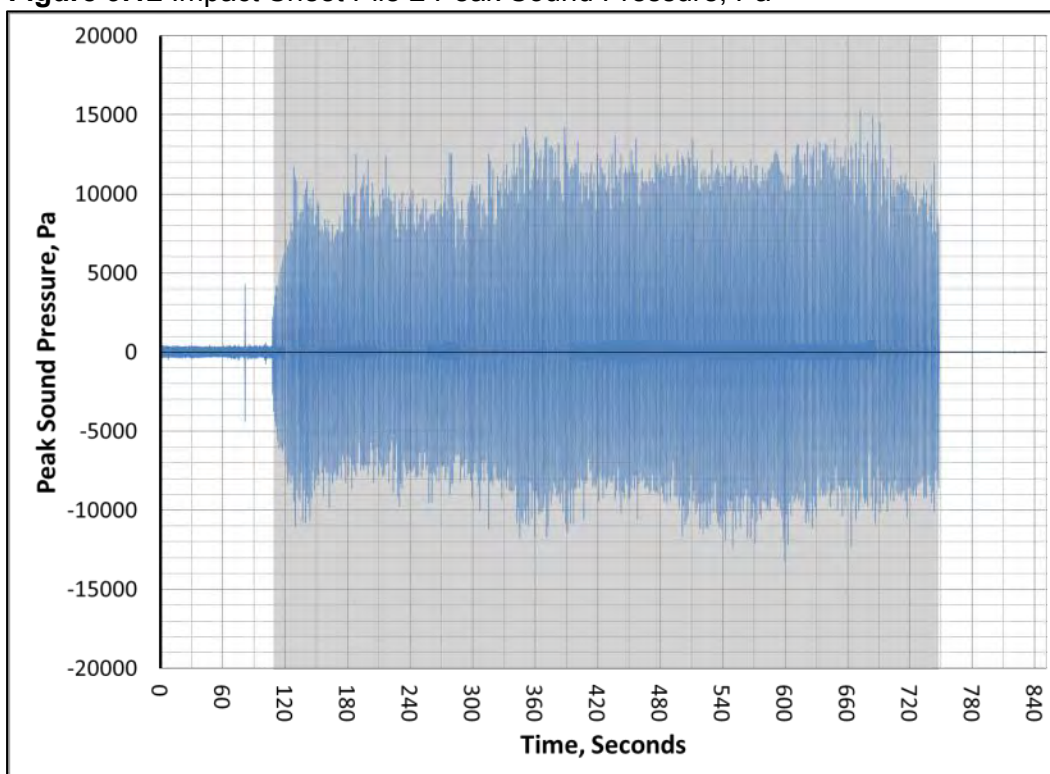
Source: The Greenbusch Group, Inc.

The data used to calculate the hydroacoustic monitoring results in Table 9.9 was from periods when impact pile driving occurred under full power. Periods when the impact hammer was not at full power and periods between pile strikes were not included in the analysis. The shaded region of Figure 9.12 illustrates periods included in the hydroacoustic analysis.

The underwater frequency spectrum shown in Figure 9.13 was measured during the highest recorded peak sound level from the impact hammer on sheet pile 2.

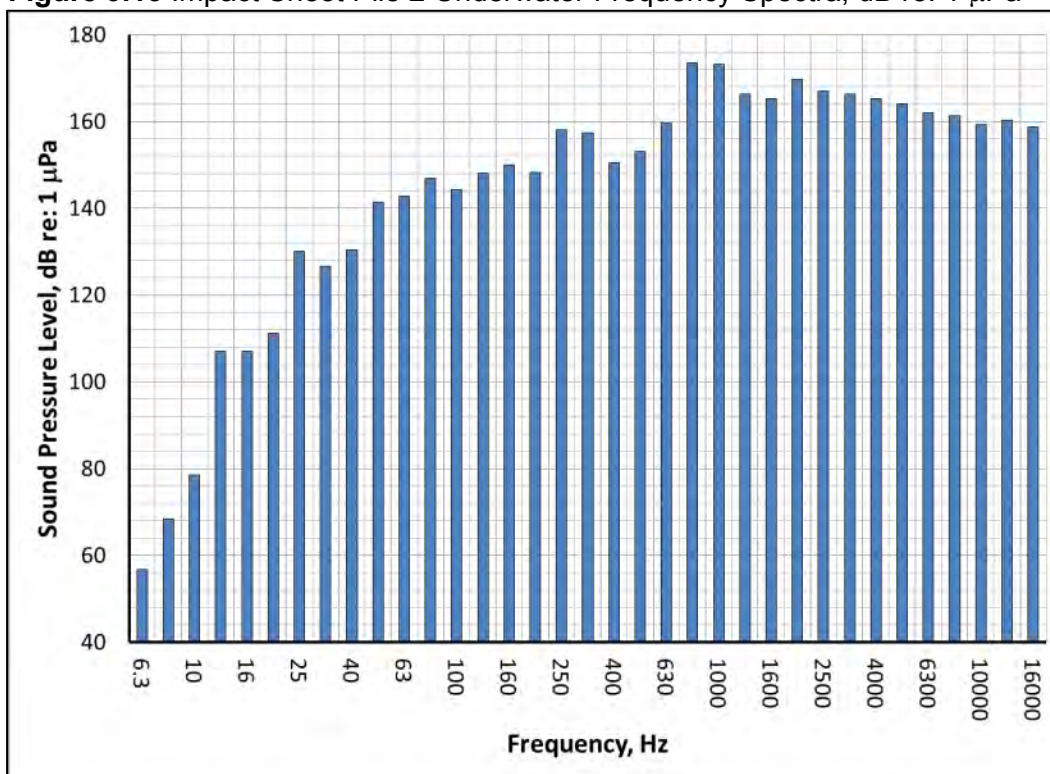
The waveform produced by the pile strike causing the highest peak sound level is provided in Figure 9.14. The shaded region of the figure indicates the section of the strike containing 90% of the acoustical energy.

**Figure 9.12** Impact Sheet Pile 2 Peak Sound Pressure, Pa



Source: The Greenbusch Group, Inc.

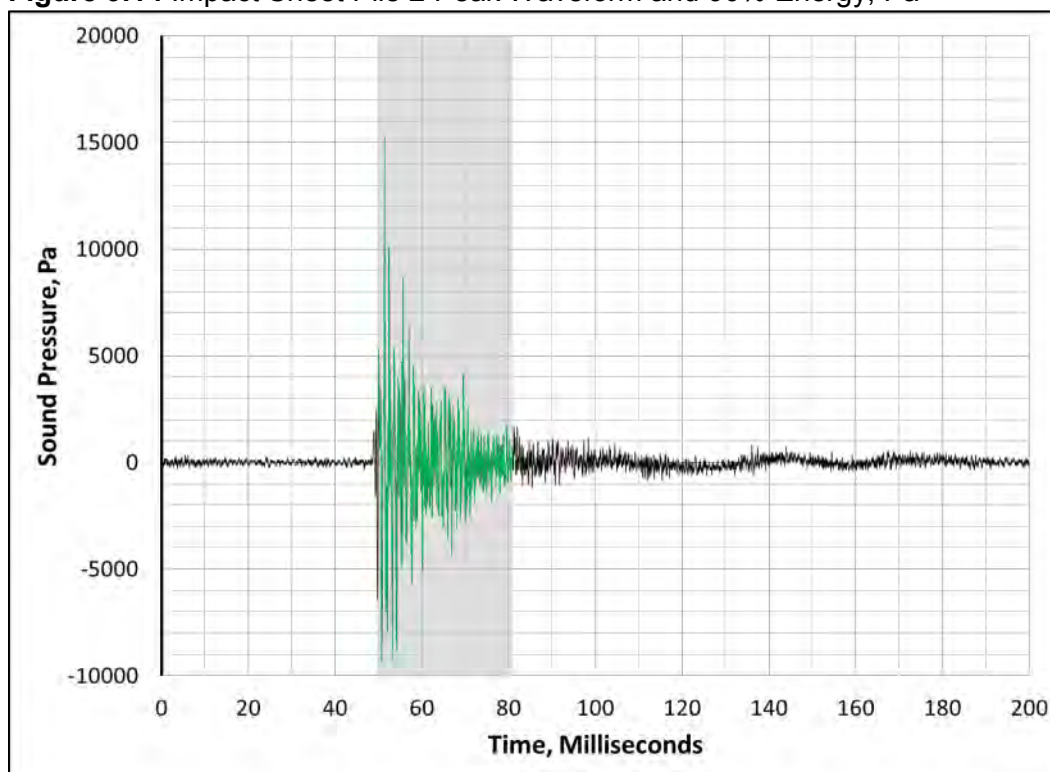
**Figure 9.13** Impact Sheet Pile 2 Underwater Frequency Spectra, dB re: 1  $\mu$ Pa



Source: The Greenbusch Group, Inc.



**Figure 9.14** Impact Sheet Pile 2 Peak Waveform and 90% Energy, Pa



Source: The Greenbusch Group, Inc.

### 9.2.2 Airborne Measurement Results

Airborne sound data was collected during the drive of the second sheet pile requiring an impact hammer. This data was analyzed to determine the range and average RMS sound levels produced over periods when the impact hammer was operating under full power. 100 millisecond RMS data was used in the analysis of airborne sound levels.

**Table 9.10** Impact Sheet Pile 2 Airborne Sound Levels, dB re: 20  $\mu$ Pa

Pile ID	Minimum	Maximum	Average
IMP-2	113	119	116

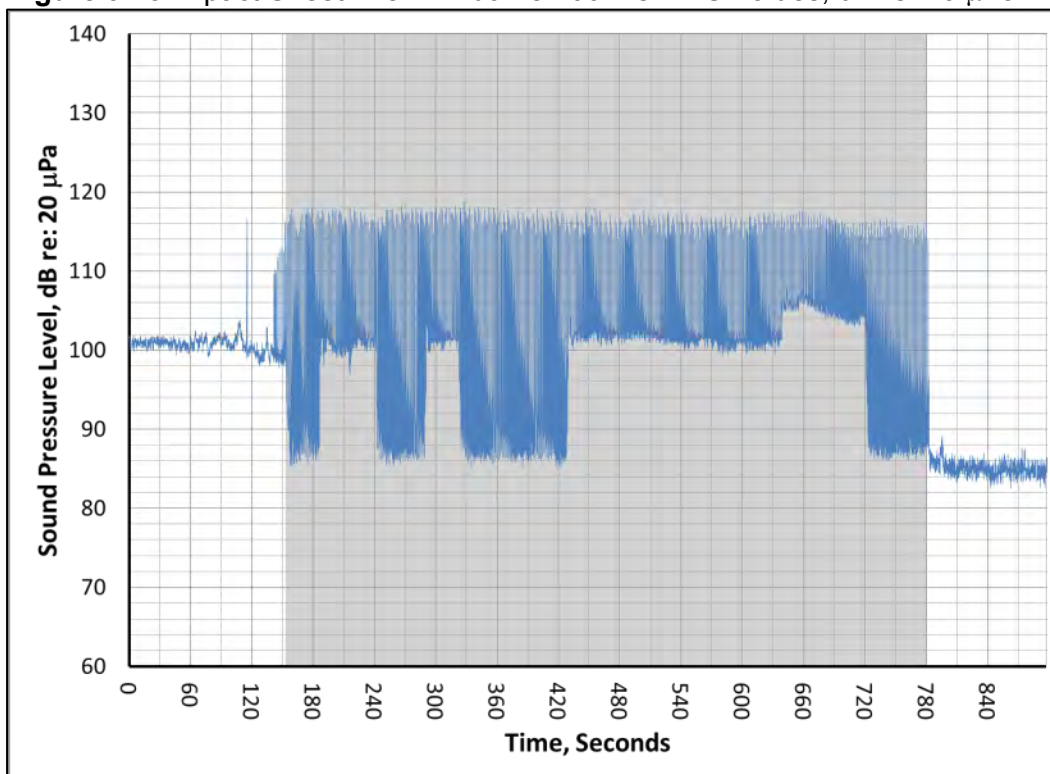
Source: The Greenbusch Group, Inc.

Results shown in Table 9.10 were calculated by only using data gathered during times when the impact hammer was operating at full power. The portions of the drive included in this airborne analysis are represented by the shaded portions of Figure 9.15. Figure 9.15 also provides the 100 millisecond RMS values measured over the entire drive.

Figure 9.16 provides a representative spectrum of airborne sound generated during by the impact pile driving.

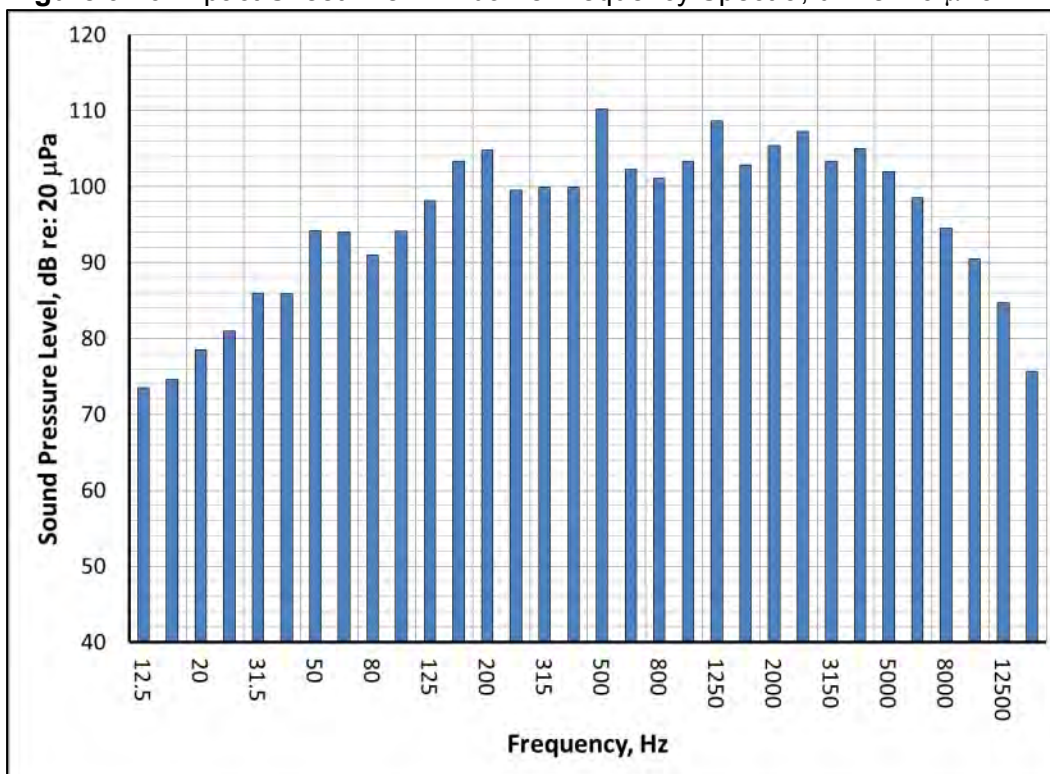


**Figure 9.15** Impact Sheet Pile 2 Airborne 100-ms RMS Values, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

**Figure 9.16** Impact Sheet Pile 2 Airborne Frequency Spectra, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

### 9.3 Impact Sheet Pile 3

The third unobstructed sheet pile requiring an impact hammer was measured on November 8, 2014. Impact pile driving began at 10:10 AM and did not include a ramp-up. At 10:15 AM pile driving was suspended because the pair of steel sheets welded together had separated and needed to be welded back together. Pile driving resumed at approximately 10:40 AM. During impact installation of this pile, vibratory pile installation was occurring simultaneously to the south. Measured sound levels were dominated by the impact hammer and audio recordings were reviewed to verify that sound generated by the vibratory hammer did not influence the measurements of the impact hammer. Table 9.11 provides information about the distance between the pile and water's edge, the water depth at the pile's location, depth the pile was driven into the substrate and the number of strikes used in the analysis.

**Table 9.11** Impact Sheet Pile 3 Information, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Number of Strikes <sup>1</sup>
IMP-3	11/8/14	None	3	20	40	972

1. Number of strikes analyzed. This number differs from the number of strikes reported in the pile logs because only pile strikes under full power were analyzed.

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Driving Logs

Measurements made of airborne sound levels were made 50 feet from the sheet pile. The microphone was located approximately 7 feet above the pier. The hydrophones were located 34 feet from the sheet pile. An unobstructed acoustical path between the both hydrophones and the sheet pile was maintained throughout the duration of the pile drive. Table 9.12 presents the water depth at the hydrophone location, depth of each hydrophone, distance between the hydrophones and the distance between the hydrophones and the sheet pile.

**Table 9.12** Impact Sheet Pile 3 Hydrophone Location Information, Feet

Pile ID	Depth at Measurement Location <sup>1</sup>	Hydrophone	Hydrophone Depth	Distance between Hydrophones	Distance to Pile
IMP-3	32	Upper	3	26	34
		Lower	29		

1. Depth at start of pile drive

Source: The Greenbusch Group, Inc. NOAA Station #9447130

The locations of the third unobstructed pile, hydrophones, and airborne sound measuring equipment are provided in Figure 9.17. Photos of impact sheet pile 3 as well as the hydrophone measurement location are provided in Figure 9.18 and Figure 9.19.

**Figure 9.17** Sheet Pile Location and Measurement Locations of Impact Sheet Pile 3



Source: The Greenbusch Group, Inc.

**Figure 9.18** Impact Sheet Pile 3



Source: The Greenbusch Group, Inc.

**Figure 9.19** Impact Sheet Pile 3 Hydrophone



Source: The Greenbusch Group, Inc.

### 9.3.1 Underwater Measurement Results

Underwater sound level data collected during the third unobstructed steel sheet pile requiring an impact hammer was analyzed to determine the range, average and standard deviation of peak, RMS<sub>90</sub> and SEL values as well as to calculate the cSEL for each marine mammal functional hearing group. This analysis was only performed over periods when the impact hammer was operating at full power. The results of the underwater noise analysis are tabulated in Table 9.13.

**Table 9.13** Impact Sheet Pile 3 Underwater Sound Levels, dB re: 1 µPa

Pile ID	Frequency Range	Peak				RMS <sub>90</sub>				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-3	7 Hz-20 kHz	189	204	2	<b>198</b>	174	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>202</b>
	75 Hz-20 kHz	189	204	2	<b>198</b>	174	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>202</b>
	150 Hz-20 kHz	189	204	2	<b>198</b>	174	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>202</b>
	200 Hz-20 kHz	189	204	2	<b>198</b>	174	189	1	<b>185</b>	162	173	1	<b>170</b>	<b>202</b>

Source: The Greenbusch Group, Inc.

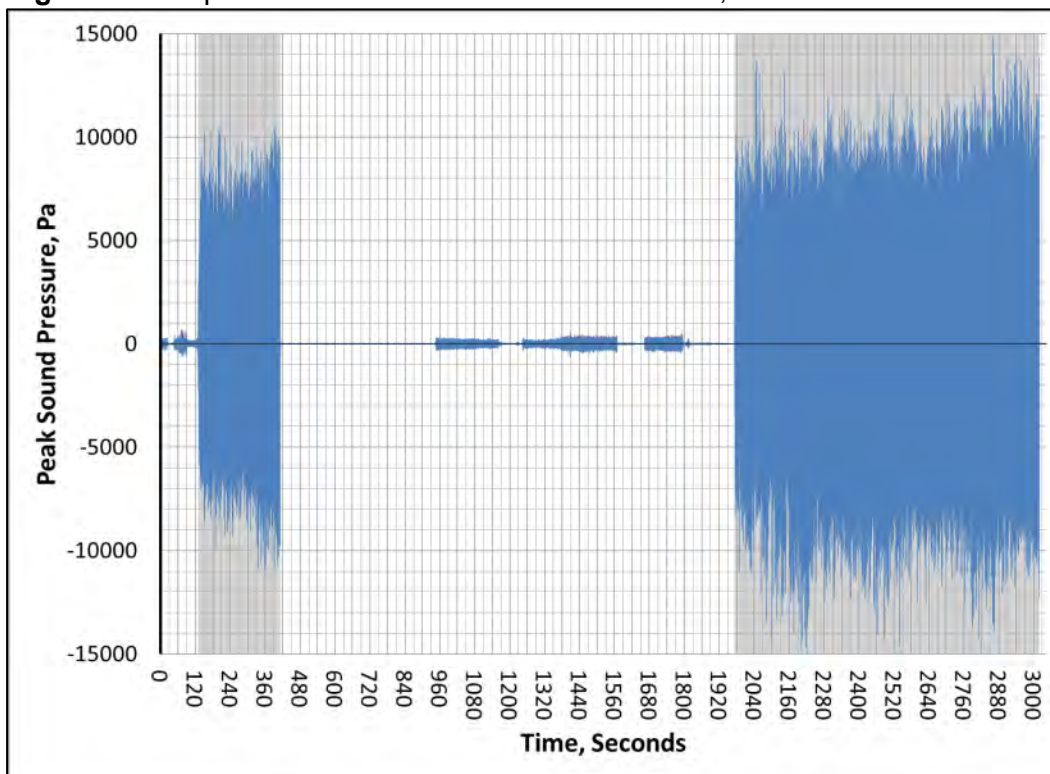
The results shown in Table 9.13 were calculated by excluding periods when the impact hammer was not operating at full power as well as periods between hammer strikes. The shaded regions of Figure 9.20 represent periods of pile driving under full power.

Figure 9.21 provides the frequency spectrum of the pile strike which generated the highest absolute peak sound pressure during the impact driving of the sheet pile.

The waveform produced by the pile strike generating the highest peak sound level is provided in Figure 9.22. The shaded region represents the portion of the pile strike containing 90% of the acoustical energy.

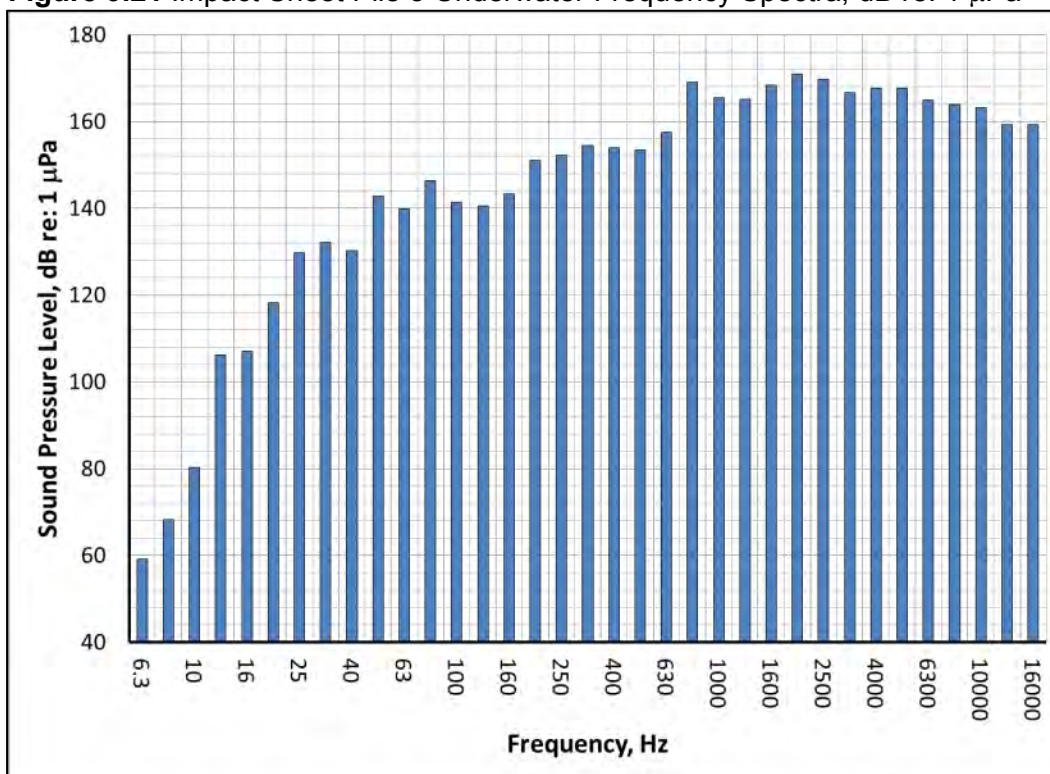


**Figure 9.20** Impact Sheet Pile 3 Peak Sound Pressure, Pa



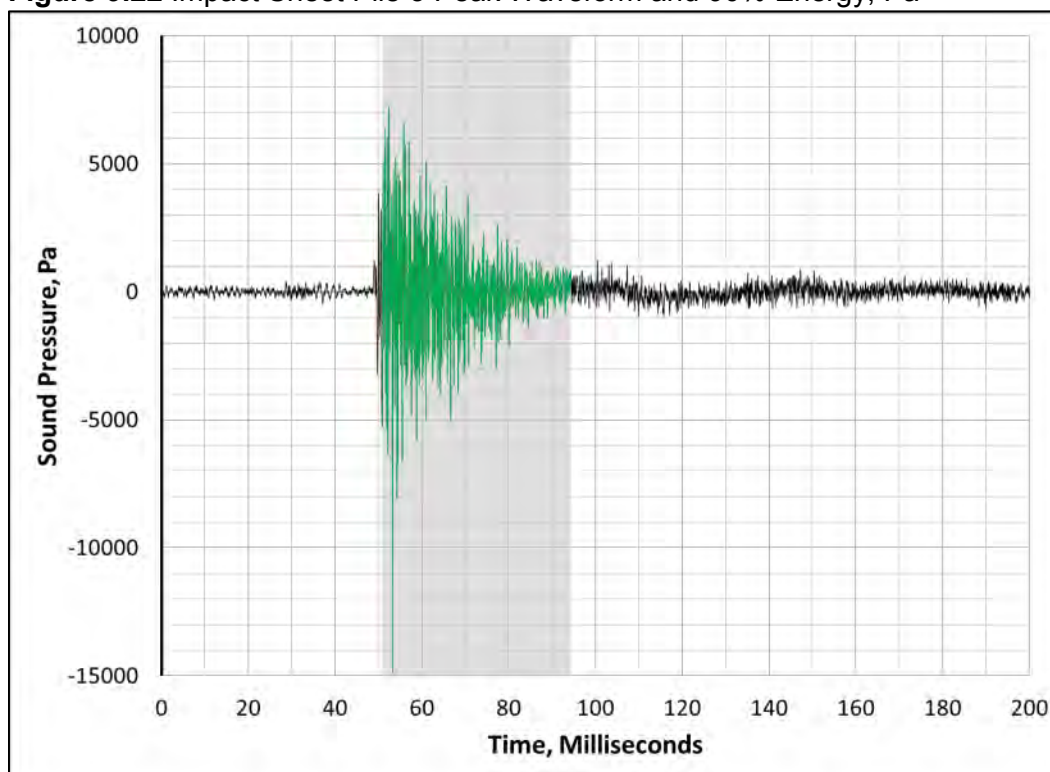
Source: The Greenbusch Group, Inc.

**Figure 9.21** Impact Sheet Pile 3 Underwater Frequency Spectra, dB re: 1  $\mu$ Pa



Source: The Greenbusch Group, Inc.

**Figure 9.22** Impact Sheet Pile 3 Peak Waveform and 90% Energy, Pa



Source: The Greenbusch Group, Inc.

### 9.3.2 Airborne Measurement Results

Airborne sound levels were recorded during the drive of the third sheet pile requiring an impact hammer. This data was analyzed to determine the range and average RMS sound levels produced over periods when the impact hammer was operating under full power using 100 millisecond RMS data. The results of this analysis are provided in Table 9.14 below.

**Table 9.14** Impact Sheet Pile 3 Airborne Sound Levels, dB re: 20  $\mu$ Pa

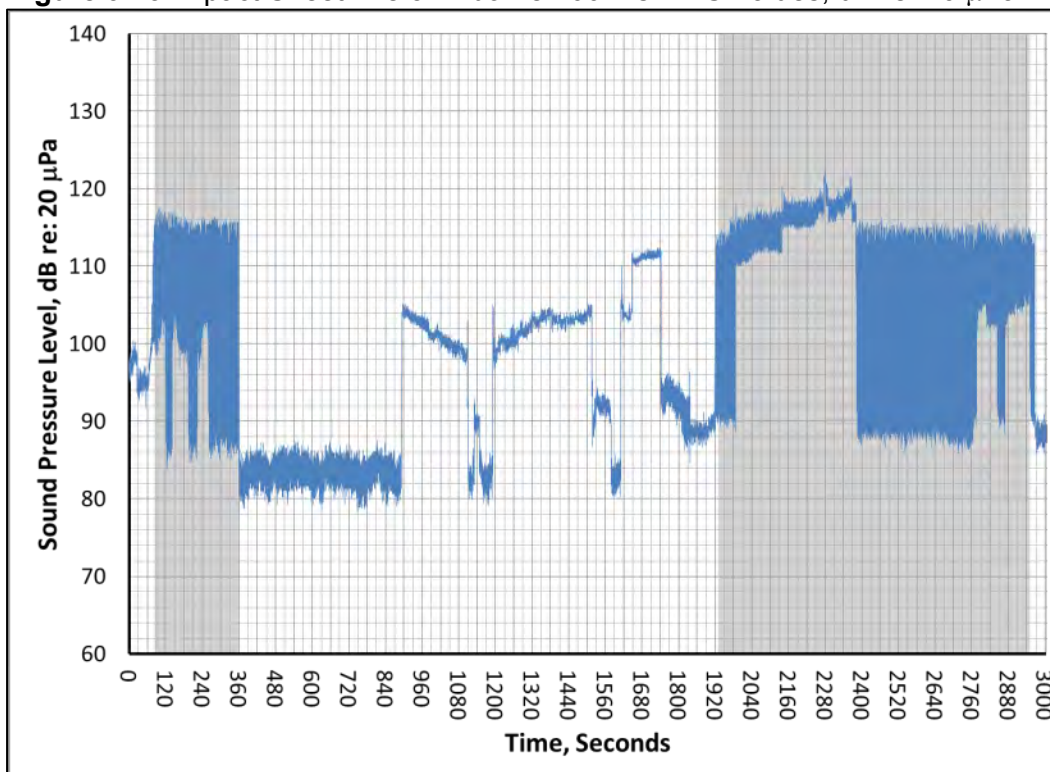
Pile ID	Minimum	Maximum	Average
IMP-3	112	122	116

Source: The Greenbusch Group, Inc.

Data collected during periods when the impact hammer was not operating at full power and data collected between pile strikes were excluded from the analysis. The portions of the pile drive that were included in the airborne sound level analysis are represented by the shaded regions of Figure 9.23. 100 millisecond RMS values collected over the duration of the pile drive are also provided in Figure 9.23. The increased airborne sound levels shown in Figure 9.23 that are not included in the analysis were generated by vibratory pile installation south of the monitoring location.

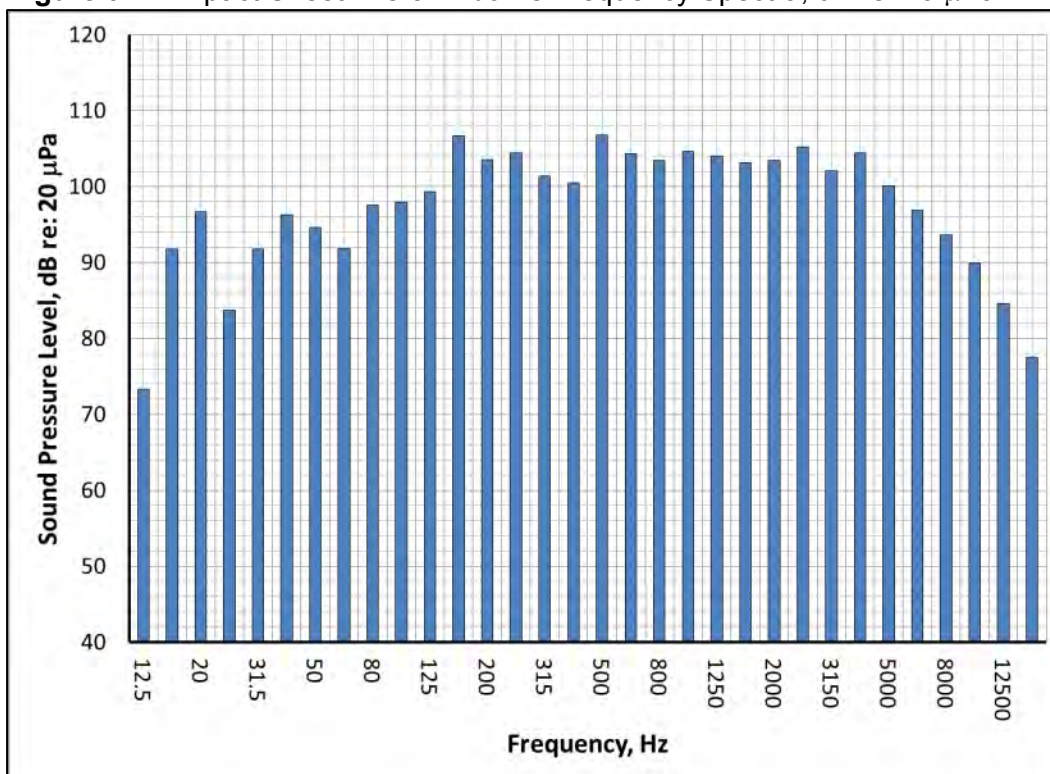
Figure 9.24 presents a representative frequency spectrum of airborne sound generated during the full powered impact hammer use.

**Figure 9.23** Impact Sheet Pile 3 Airborne 100-ms RMS Values, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

**Figure 9.24** Impact Sheet Pile 3 Airborne Frequency Spectra, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

## 9.4 Impact Sheet Pile 4

The fourth steel sheet pile that required driving with an impact hammer was driven on November 8, 2014. Impact pile driving began at 11:40 AM and did not include a ramp-up. An unobstructed acoustical transmission path was maintained during the entire drive. Table 9.15 presented information on the distance from the pile to the water's edge, water depth at the sheet pile's location, depth into the substrate the pile was driven and the number of strike included in the hydroacoustic analysis.

**Table 9.15** Impact Sheet Pile 4 Information, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Number of Strikes <sup>1</sup>
IMP-4	11/8/14	None	3	18	42	652

1. Number of strikes analyzed. This number differs from the number of strikes reported in the pile logs because only pile strikes under full power were analyzed.

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Driving Logs

Airborne sound levels were measured 50 feet from the sheet pile. The microphone was positioned approximately 7 feet above the pier. The hydrophones were located 35 feet away from the pile and an unobstructed acoustical path was maintained to the pile over the duration of the drive. Table 9.16 below provides the water depth at the hydrophone locations, vertical distance between the hydrophones and the distance between the sheet pile and the hydrophones.

**Table 9.16** Impact Sheet Pile 4 Hydrophone Location Information, Feet

Pile ID	Depth at Measurement Location <sup>1</sup>	Hydrophone	Hydrophone Depth	Distance between Hydrophones	Distance to Pile
IMP-4	31	Upper	3	25	35
		Lower	28		

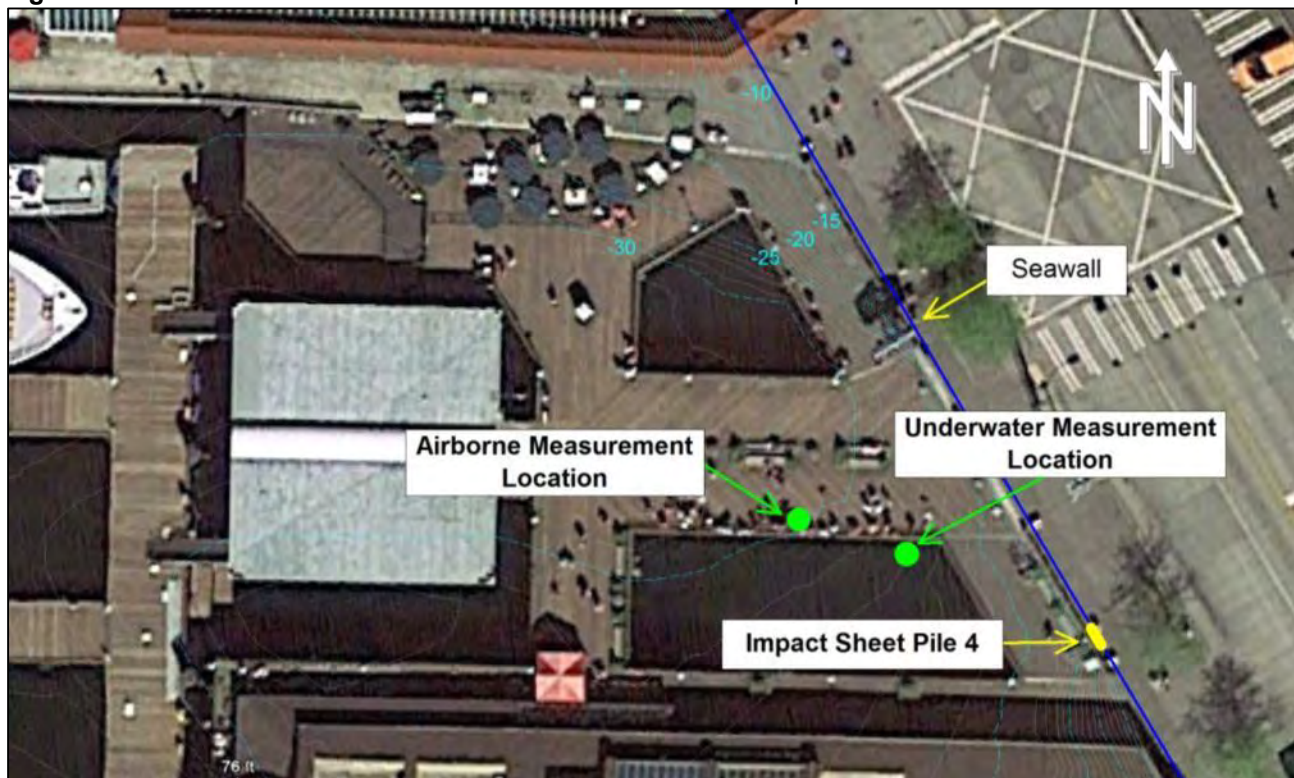
1. Depth at start of pile drive

Source: The Greenbusch Group, Inc. NOAA Station #9447130

The locations of the fourth unobstructed pile, hydrophones, and airborne sound measuring equipment are provided in Figure 9.25. Photos of the sheet pile and the hydrophone location are provided in Figure 9.26 and Figure 9.27.



**Figure 9.25** Sheet Pile Location and Measurement Locations of Impact Sheet Pile 4



Source: The Greenbusch Group, Inc.

**Figure 9.26** Impact Sheet Pile 4



Source: The Greenbusch Group, Inc.

**Figure 9.27** Impact Sheet Pile 4 Hydrophone



Source: The Greenbusch Group, Inc.

#### 9.4.1 Underwater Measurement Results

Underwater sound data was collected during the drive of the fourth unobstructed sheet pile requiring an impact hammer. This data was analyzed to determine the range, average and standard deviation of peak, RMS<sub>90</sub> and SEL values as well to determine the cSEL for all marine mammal functional hearing groups during full powered operation of the impact hammer. The results of the hydroacoustic analysis are provided in Table 9.17.

**Table 9.17** Impact Sheet Pile 4 Underwater Sound Levels, dB re: 1  $\mu$ Pa

Pile ID	Frequency Range	Peak				RMS <sub>90</sub>				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-4	7 Hz-20 kHz	191	202	1	<b>197</b>	178	187	1	<b>184</b>	165	172	1	<b>169</b>	<b>199</b>
	75 Hz-20 kHz	191	202	1	<b>197</b>	179	187	1	<b>184</b>	164	172	1	<b>169</b>	<b>198</b>
	150 Hz-20 kHz	192	202	1	<b>197</b>	179	187	1	<b>184</b>	164	172	1	<b>169</b>	<b>198</b>
	200 Hz-20 kHz	192	202	1	<b>197</b>	179	187	1	<b>184</b>	164	172	1	<b>169</b>	<b>198</b>

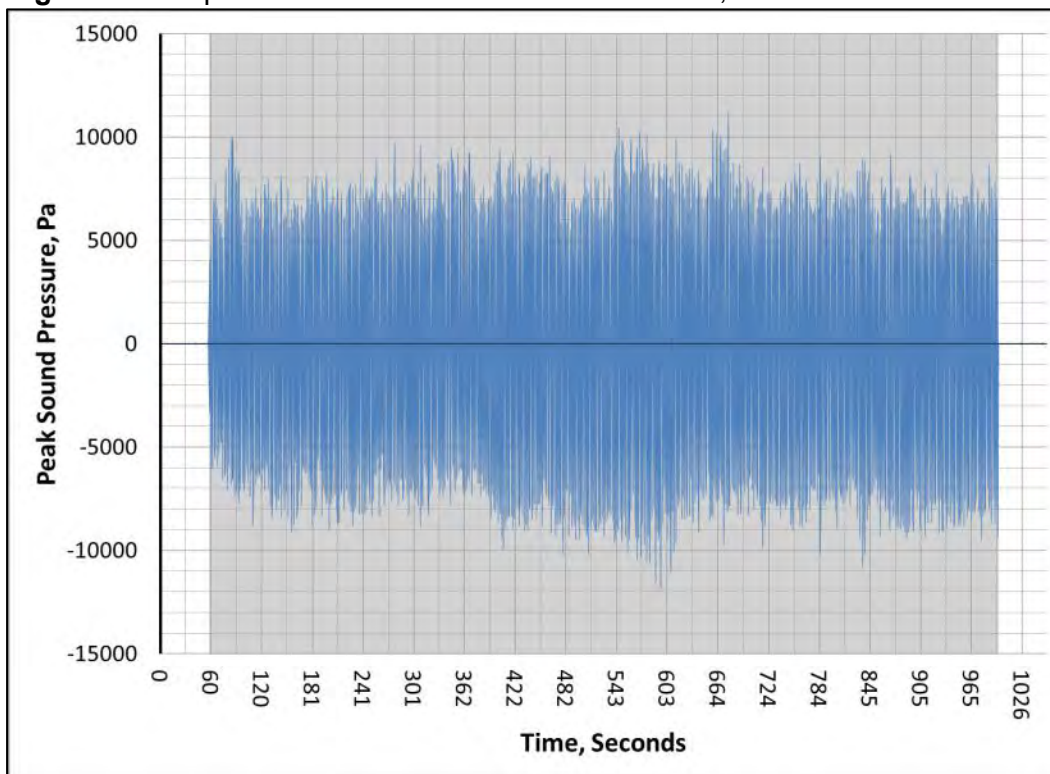
Source: The Greenbusch Group, Inc.

Periods when the impact hammer was not operating at full power were excluded from the analysis used to calculate the results in Table 9.17. The periods included in the hydroacoustic analysis are represented by the shaded regions of Figure 9.28 below.

The underwater frequency spectrum shown in Figure 9.29 was measured during the highest recorded peak sound level during the drive of impact sheet pile 4.

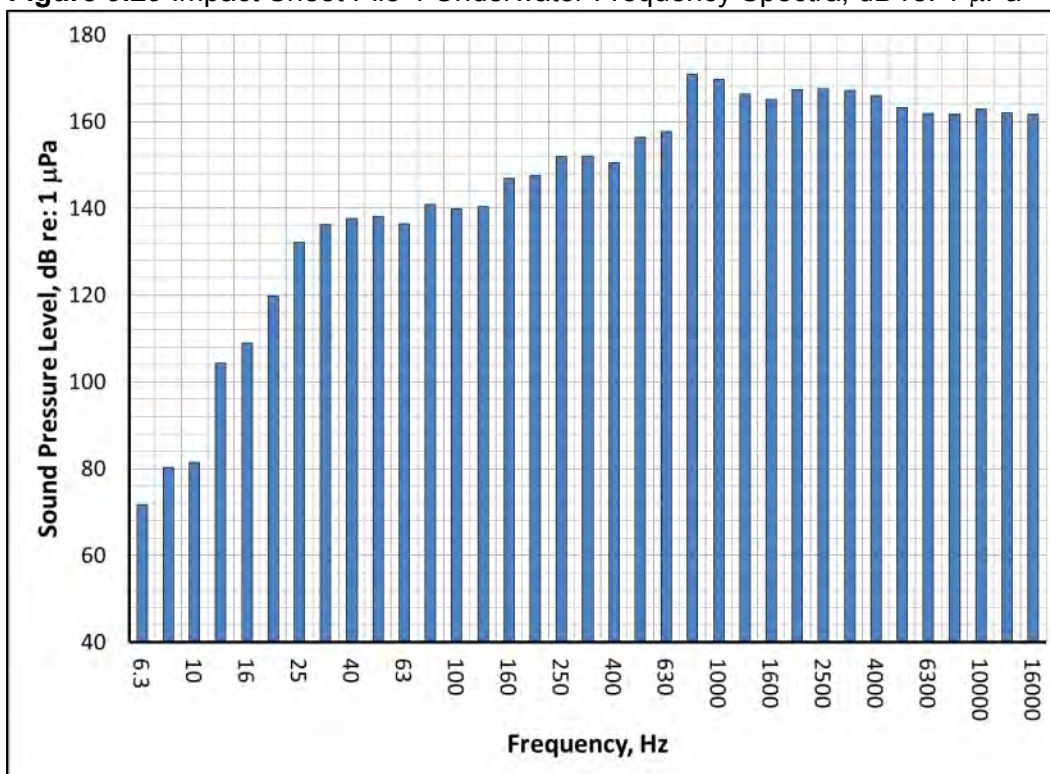
The waveform generated by the pile strike causing the highest peak sound level is provided in Figure 9.30. The shaded region of the Figure 9.30 illustrates the portion of the pile strike containing 90% of the acoustical energy.

**Figure 9.28** Impact Sheet Pile 4 Peak Sound Pressure, Pa



Source: The Greenbusch Group, Inc.

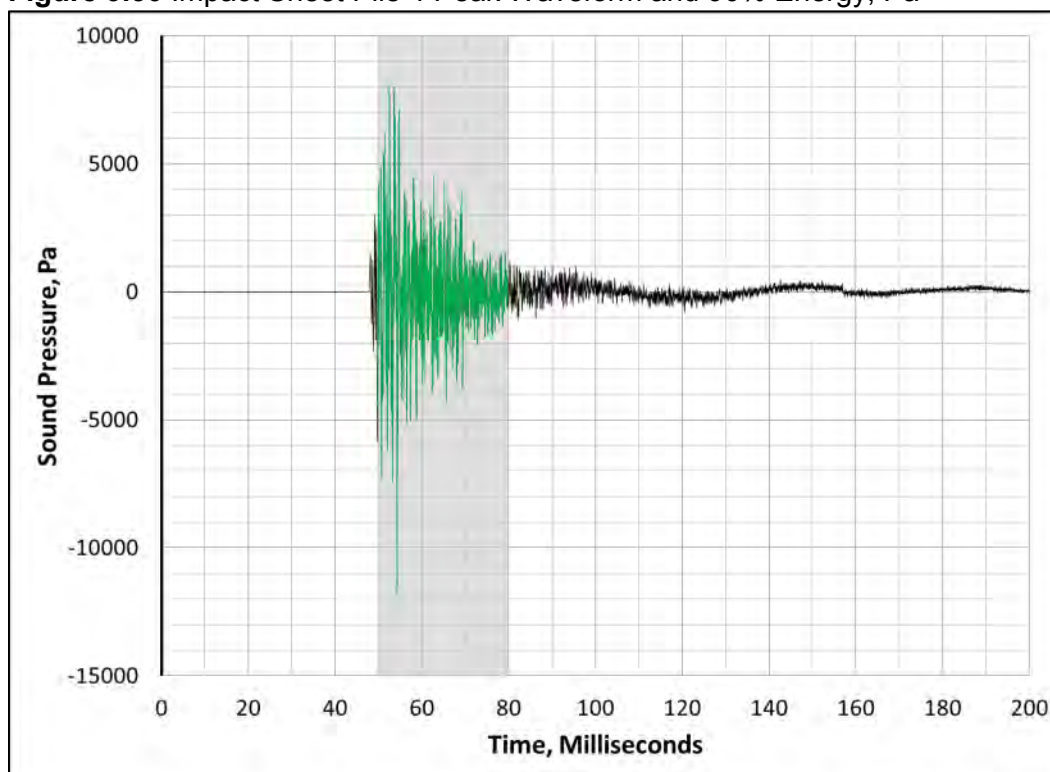
**Figure 9.29** Impact Sheet Pile 4 Underwater Frequency Spectra, dB re: 1  $\mu$ Pa



Source: The Greenbusch Group, Inc.



**Figure 9.30** Impact Sheet Pile 4 Peak Waveform and 90% Energy, Pa



Source: The Greenbusch Group, Inc.

#### 9.4.2 Airborne Measurement Results

Airborne sound levels were measured during the drive of impact sheet pile 4. The measurement data was analyzed to determine the range and average RMS sound levels generated over periods when the impact hammer was operating at full power. 100 millisecond RMS data was utilized for the analysis of airborne sound levels.

**Table 9.18** Impact Sheet Pile 4 Airborne Sound Levels, dB re: 20  $\mu$ Pa

Pile ID	Minimum	Maximum	Average
IMP-4	111	119	114

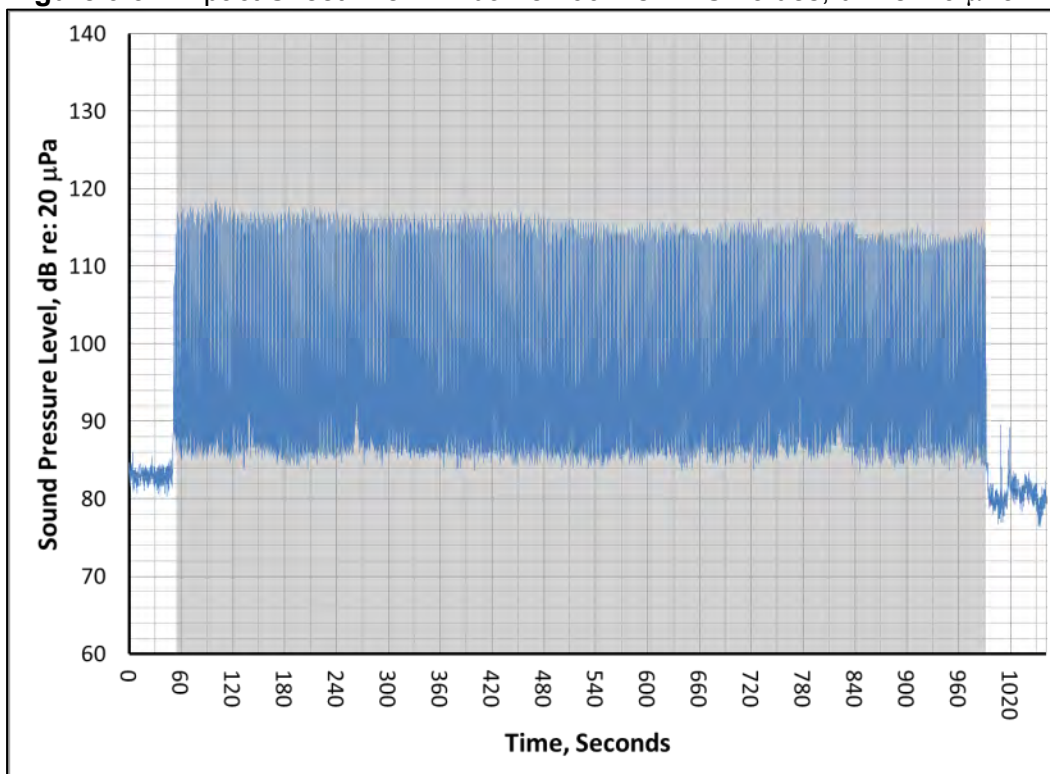
Source: The Greenbusch Group, Inc.

The results provided in Table 9.18 were calculated by only using data collected during times when the impact hammer was operating at full power. The portions of the drive where the hammer was not operating at full power, as well as the periods between pile strikes, are excluded from the analysis. The portions of the drive that were included in the calculation of airborne sound levels are represented by the shaded regions of Figure 9.31, which also provides the 100 millisecond RMS values collected over the entire drive.

Figure 9.32 presents a representative airborne frequency spectrum of sound produced during impact pile driving under full power.

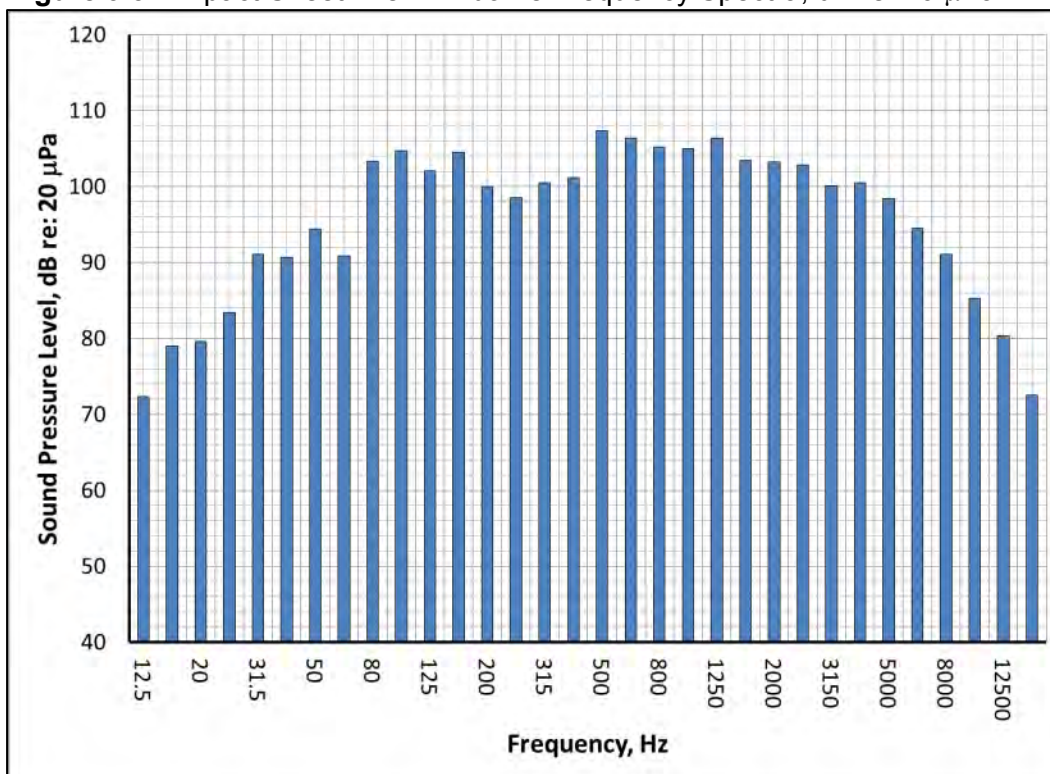


**Figure 9.31** Impact Sheet Pile 4 Airborne 100-ms RMS Values, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

**Figure 9.32** Impact Sheet Pile 4 Airborne Frequency Spectra, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

## 9.5 Impact Sheet Pile 5

The fifth unobstructed steel sheet pile that required an impact hammer was monitored on November 8, 2014. The impact pile driving began at 12:45 PM, which did not include a ramp-up. Table 9.19 tabulates the distance between the pile and the water's edge, the water depth at the pile, the depth the sheet pile was driven into the substrate and the number of strike included in the hydroacoustic analysis.

**Table 9.19** Impact Sheet Pile 5 Information, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Depth Driven into Substrate	Number of Strikes <sup>1</sup>
IMP-5	11/8/14	None	3	16	44	889

1. Number of strikes analyzed. This number differs from the number of strikes reported in the pile logs because only pile strikes under full power were analyzed.

Source: The Greenbusch Group, Inc. Mortenson/Manson Pile Driving Logs

Airborne sound data was also collected 50 feet from the sheet pile. The microphone was positioned approximately 7 feet above the pier. The two hydrophones were deployed 33 feet from the sheet pile. An unobstructed sound transmission path was maintained between the two hydrophones and the sheet pile over the entire duration of the drive. Table 9.20 presents the water depth at the hydrophone locations, the depth of both hydrophones, the vertical distance between the hydrophones and the distance between the sheet pile and hydrophones.

**Table 9.20** Impact Sheet Pile 5 Hydrophone Location Information, Feet

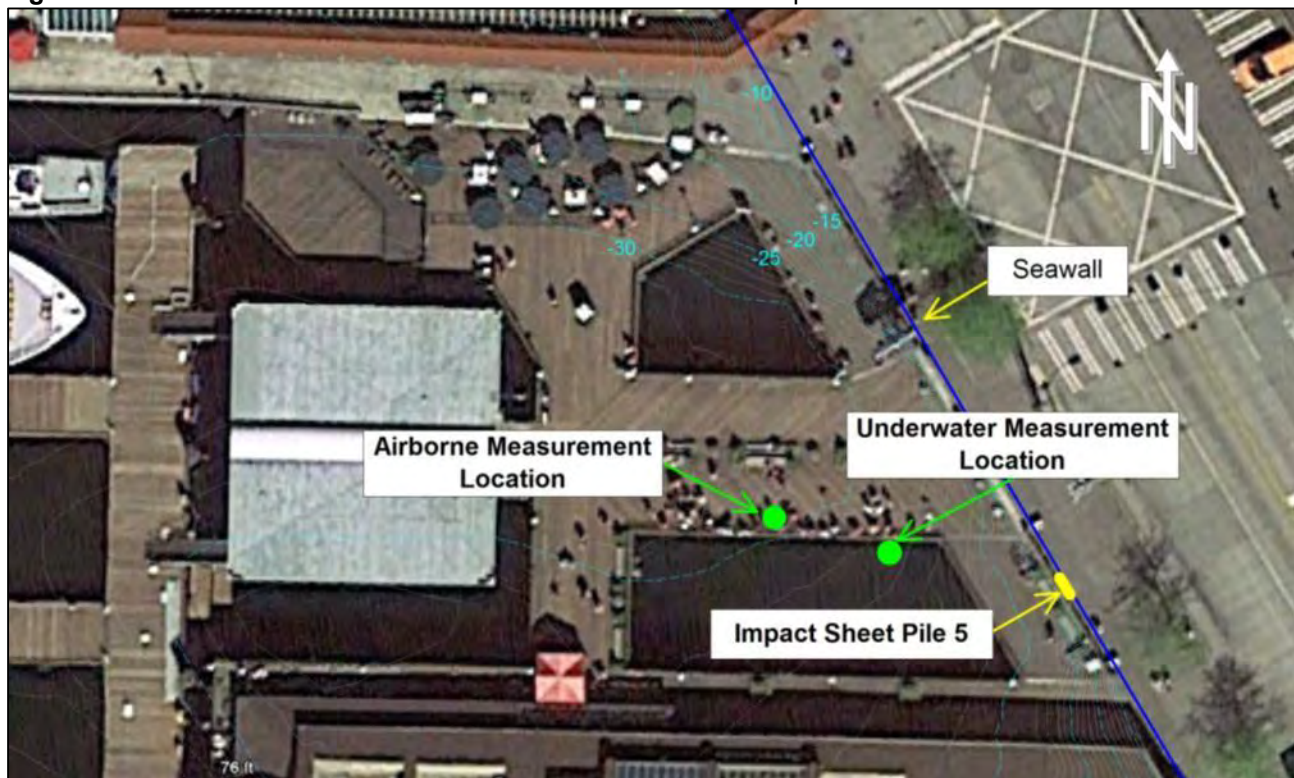
Pile ID	Depth at Measurement Location <sup>1</sup>	Hydrophone	Hydrophone Depth	Distance between Hydrophones	Distance to Pile
IMP-5	32	Upper	3	25	33
		Lower	28		

1. Depth at start of pile drive

Source: The Greenbusch Group, Inc. NOAA Station #9447130

The locations of the sheet pile, hydrophones and airborne sound monitoring equipment are provided in Figure 9.33. Photos of the sheet pile and hydrophone measurement locations are shown in Figure 9.34 and Figure 9.35.

**Figure 9.33** Sheet Pile Location and Measurement Locations of Impact Sheet Pile 5



Source: The Greenbusch Group, Inc.

**Figure 9.34** Impact Sheet Pile 5



Source: The Greenbusch Group, Inc.

**Figure 9.35** Impact Sheet Pile 5 Hydrophone



Source: The Greenbusch Group, Inc.

### 9.5.1 Underwater Measurement Results

Underwater sound levels collected during the fifth unobstructed steel sheet pile requiring an impact hammer was used to determine the range, average and standard deviation of peak, RMS<sub>90</sub> and SEL values as well as to calculate the cSEL for each marine mammal functional hearing group. The analysis was conducted over periods when the impact hammer was operating at full power. The results of the hydroacoustic analysis are provided in Table 9.21.

**Table 9.21** Impact Sheet Pile 5 Underwater Sound Levels, dB re: 1  $\mu$ Pa

Pile ID	Frequency Range	Peak				RMS <sub>90</sub>				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-5	7 Hz-20 kHz	190	204	1	<b>197</b>	177	188	1	<b>184</b>	163	173	1	<b>170</b>	<b>201</b>
	75 Hz-20 kHz	190	203	1	<b>197</b>	177	188	1	<b>184</b>	165	173	1	<b>170</b>	<b>201</b>
	150 Hz-20 kHz	191	202	1	<b>197</b>	177	188	1	<b>184</b>	163	173	1	<b>170</b>	<b>201</b>
	200 Hz-20 kHz	190	203	1	<b>197</b>	177	188	1	<b>184</b>	163	173	1	<b>170</b>	<b>201</b>

Source: The Greenbusch Group, Inc.

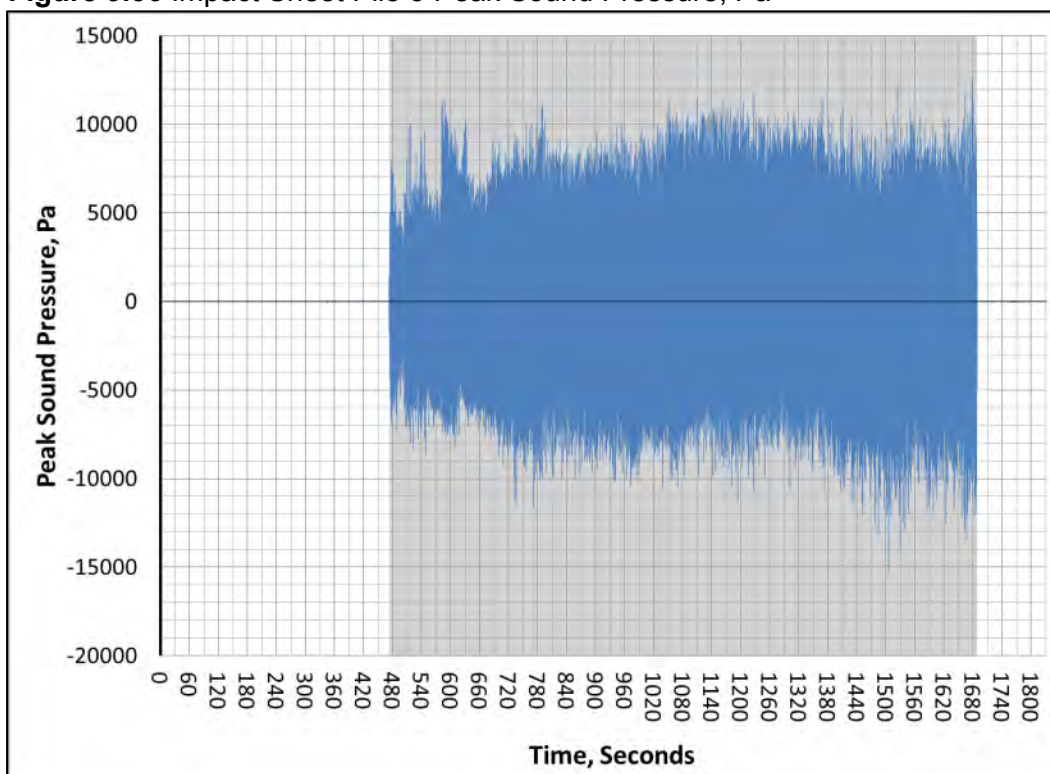
The results shown in the Table above were calculated by only including data collected during times of full powered impact pile driving. Data collected when the impact hammer was not operating at full power as well as data collected between pile strikes was excluded from the analysis. The shaded portions of Figure 9.36 illustrate the periods where data was included in the analysis.

Figure 9.37 presents the frequency spectrum of the pile strike that produced the highest absolute peak sound pressure during the drive.

The waveform generated by the pile strike that produced the highest peaks sound level measured during the drive is shown in Figure 9.38. The shaded region of Figure 9.38 represents the portion of the strike containing 90% of the acoustical energy.

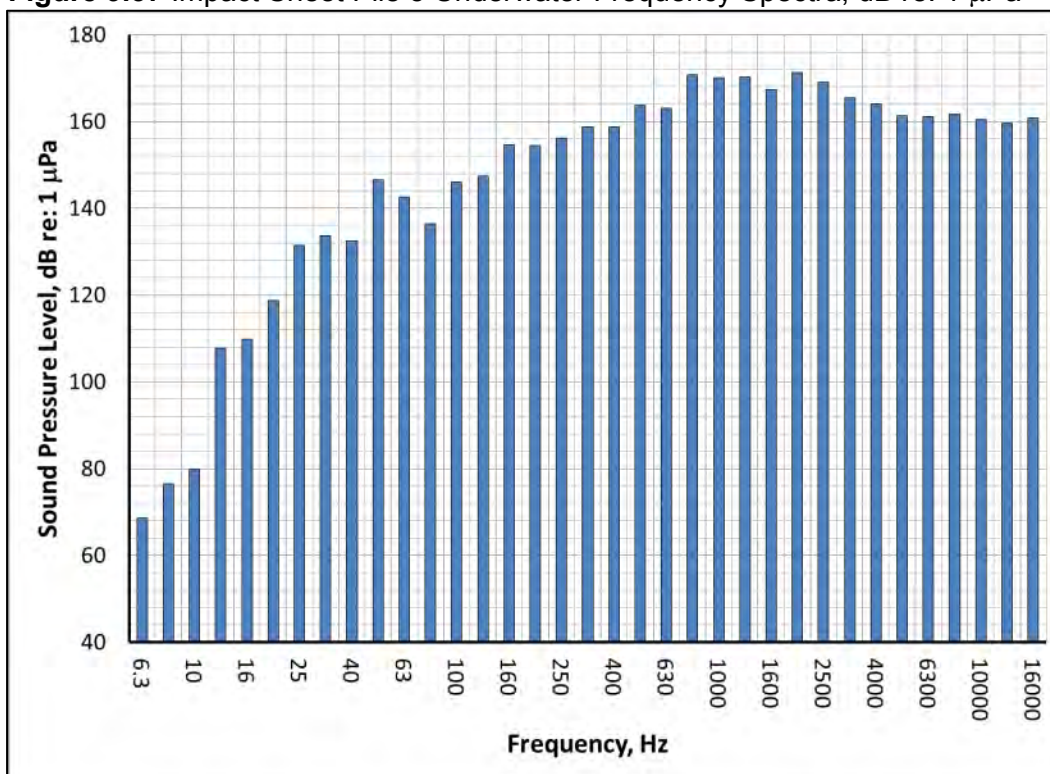


**Figure 9.36** Impact Sheet Pile 5 Peak Sound Pressure, Pa



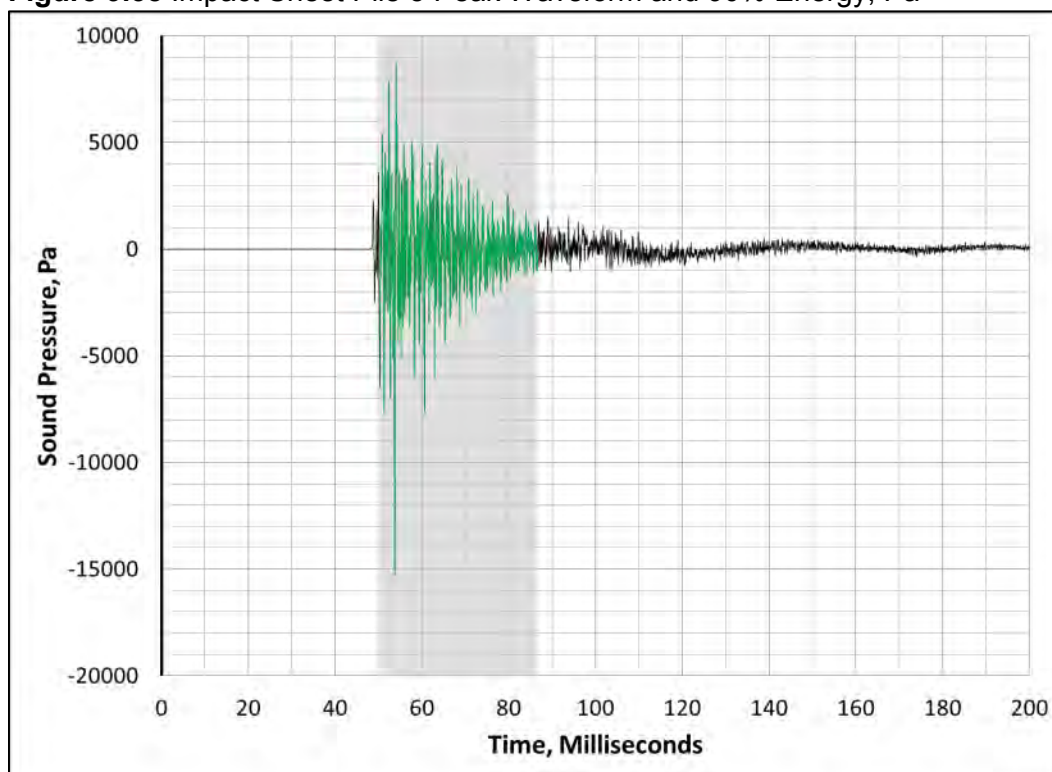
Source: The Greenbusch Group, Inc.

**Figure 9.37** Impact Sheet Pile 5 Underwater Frequency Spectra, dB re: 1  $\mu$ Pa



Source: The Greenbusch Group, Inc.

**Figure 9.38** Impact Sheet Pile 5 Peak Waveform and 90% Energy, Pa



Source: The Greenbusch Group, Inc.

### 9.5.2 Airborne Measurement Results

Airborne sound levels were measured during the drive of the fifth sheet pile driven with an impact hammer. This data was analyzed to determine the range and average RMS sound levels produced over periods when the impact hammer was operating under full power using 100 millisecond RMS data. The results of the analysis are presented in Table 9.22 below.

**Table 9.22** Impact Sheet Pile 5 Airborne Sound Levels, dB re: 20  $\mu$ Pa

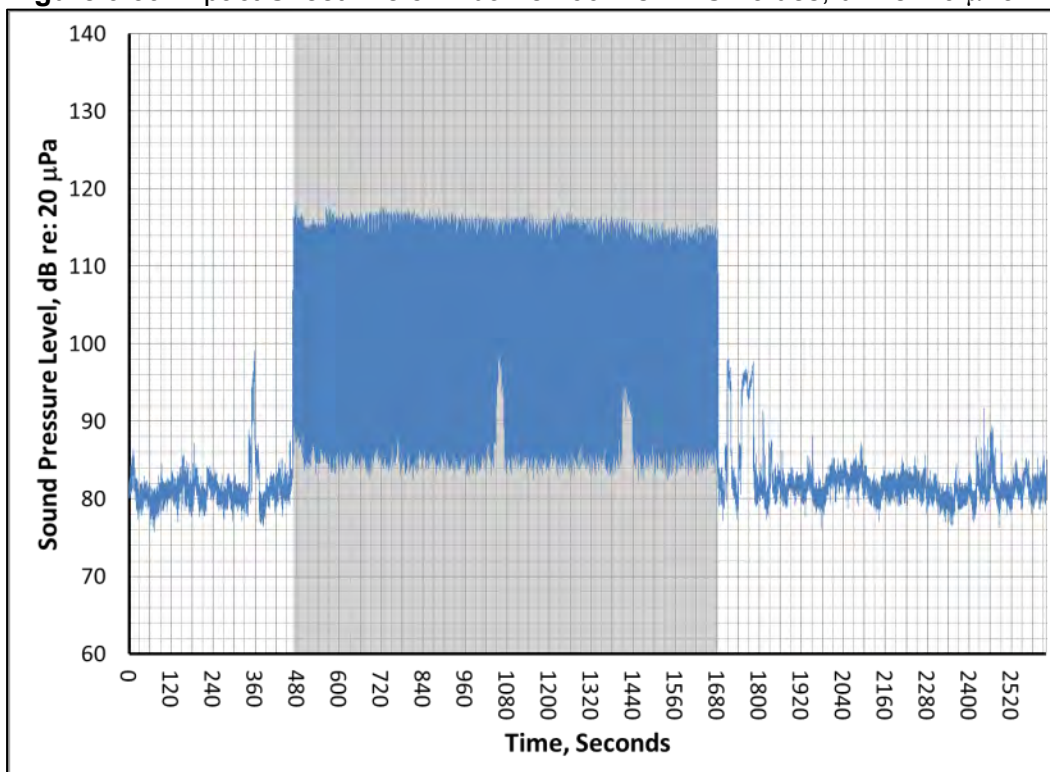
Pile ID	Minimum	Maximum	Average
IMP-5	112	118	115

Source: The Greenbusch Group, Inc.

Data collected during periods when the impact hammer was not operating at full power and data collected between pile strikes were excluded from the analysis. The portions of the pile drive that were included in the airborne sound level analysis are represented by the shaded regions of Figure 9.39. 100 millisecond RMS values collected over the duration of the pile drive are also provided in Figure 9.39.

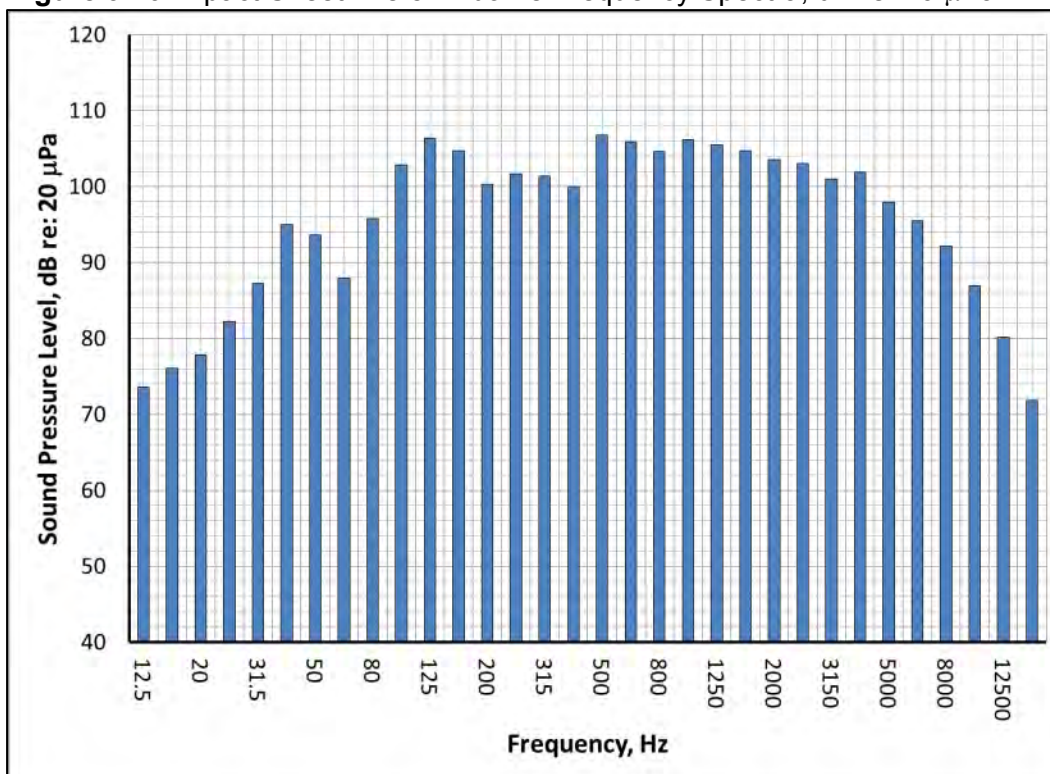
Figure 9.40 provides a representative frequency spectrum of airborne sound produced during the full powered impact pile driving.

**Figure 9.39** Impact Sheet Pile 5 Airborne 100-ms RMS Values, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

**Figure 9.40** Impact Sheet Pile 5 Airborne Frequency Spectra, dB re: 20  $\mu$ Pa



Source: The Greenbusch Group, Inc.

## 10.0 MARINE MAMMAL DETECTION DISTANCES AND DISTANCE TO BACKGROUND SOUND LEVELS

Background underwater sound level measurements were used in conjunction with data collected during pile driving activities to estimate the distance required for underwater sound levels generated from pile driving to reach the marine mammal detection thresholds and existing background sound levels.

The National Marine Fisheries Service (NMFS) has defined underwater sound level thresholds for the disturbance and injury of marine mammals. These thresholds are provided in Table 10.1.

**Table 10.1** Marine Mammal Disturbance Thresholds, dB re: 1  $\mu$ Pa (RMS)

Functional Hearing Group	Frequency Range	Underwater Sound Thresholds		
		Vibratory Pile Driving Disturbance Threshold (Level B)	Impact Pile Driving Disturbance Threshold (Level B)	Injury Threshold (Level A)
Cetaceans (small to large)	7 Hz-20 kHz	120	160	180
	150 Hz-20 kHz			
	200 Hz-20 kHz			
Pinnipeds	75 Hz-20 kHz	120	160	190

Source: National Marine Fisheries Service

The distance required for underwater sound generated by vibratory and impact pile driving of steel sheet piles to reach the marine mammal disturbance and injury thresholds presented in Table 10.1 were calculated using the “practical spreading model” currently used by WSDOT and NOAA. The practical spreading formula is provided below.

$$SPL_{D_2} = SPL_{D_1} + 15 * \log_{10} \left( \frac{D_1}{D_2} \right)$$

Where  $SPL_{D_1}$  is the sound pressure measured at a distance,  $D_1$  and  $SPL_{D_2}$  is the estimated sound pressure at a distance,  $D_2$ . The distance required for underwater sound produced by pile driving is estimated by solving the formula above for  $D_2$  resulting in the following:

$$D_2 = D_1 * 10^{\left( \frac{SPL_{D_1} - SPL_{D_2}}{15} \right)}$$

The highest measured average RMS sound levels from vibratory and impact driving of steel sheet piles were used to calculate the distance required for sound to reach the marine mammal disturbance and injury thresholds and the background sound levels measured by WSDOT.



## 10.1 Marine Mammal Detection and Injury Distances

The distances required for underwater sound levels to attenuate down to the marine mammal disturbance and injury thresholds were calculated using the Practical Spreading Model and the highest average RMS sound levels measured during vibratory and impact pile installation. The resulting distances from vibratory and impact pile driving of steel sheet piles are shown in Table 10.2.

**Table 10.2** Distances to Marine Mammal Thresholds from Pile Driving

Functional Hearing Group	Frequency Range	RMS	Marine Mammal Detection Thresholds		Distance to Threshold	
			Disturbance (Level B)	Injury (Level A)	Disturbance (Level B)	Injury (Level A)
Vibratory Pile Driving						
Cetaceans (small to large)	7 Hz-20 kHz	168	120 <sup>1</sup>	180	9.9 miles	N/A
	150 Hz-20 kHz	168				
	200 Hz-20 kHz	168				
Pinnipeds	75 Hz-20 kHz	168	120 <sup>1</sup>	190	9.9 miles	N/A
Impact Pile Driving						
Cetaceans (small to large)	7 Hz-20 kHz	185	160	180	1,532 feet	71 feet
	150 Hz-20 kHz	185				
	200 Hz-20 kHz	185				
Pinnipeds	75 Hz-20 kHz	185	160	190	1,532 feet	N/A

1. Background sound levels exceed the 120 dB disturbance threshold for vibratory pile driving.

Source: The Greenbusch Group, Inc.

As shown in Table 10.2, the distance required for sound created by vibratory pile driving to reach the 120 dB marine mammal disturbance threshold is 9.9 miles. However, the underwater sound resulting from vibratory pile driving will encounter landmasses closer to the project site, limiting the extent of the underwater sound. Figure 10.1 presents the areas where underwater sound levels exceed the marine mammal disturbance thresholds (120 dB for vibratory pile driving and 160 dB for impact pile driving).

**Figure 10.1** Marine Mammal Disturbance Zones



Source: The Greenbusch Group, Inc.

## 10.2 Distance to Background Sound Levels

In addition to calculating the distance required for underwater sound levels to reach the marine mammal detection distances (Level B), the distances required to reach background sound levels were also calculated. These distances to background sound levels were calculated using the background sound levels measured by WSDOT in April 2011. The WSDOT data was used rather than the near shore data collected by Greenbusch in 2015 because the WSDOT data more accurately describes the environment where marine mammals are likely to be present.

### 10.2.1 Distance to Far Field Background Sound Levels

The distance required for underwater sound to attenuate to the background sound levels measured by WSDOT in April 2011 are provided in Table 10.3 below.

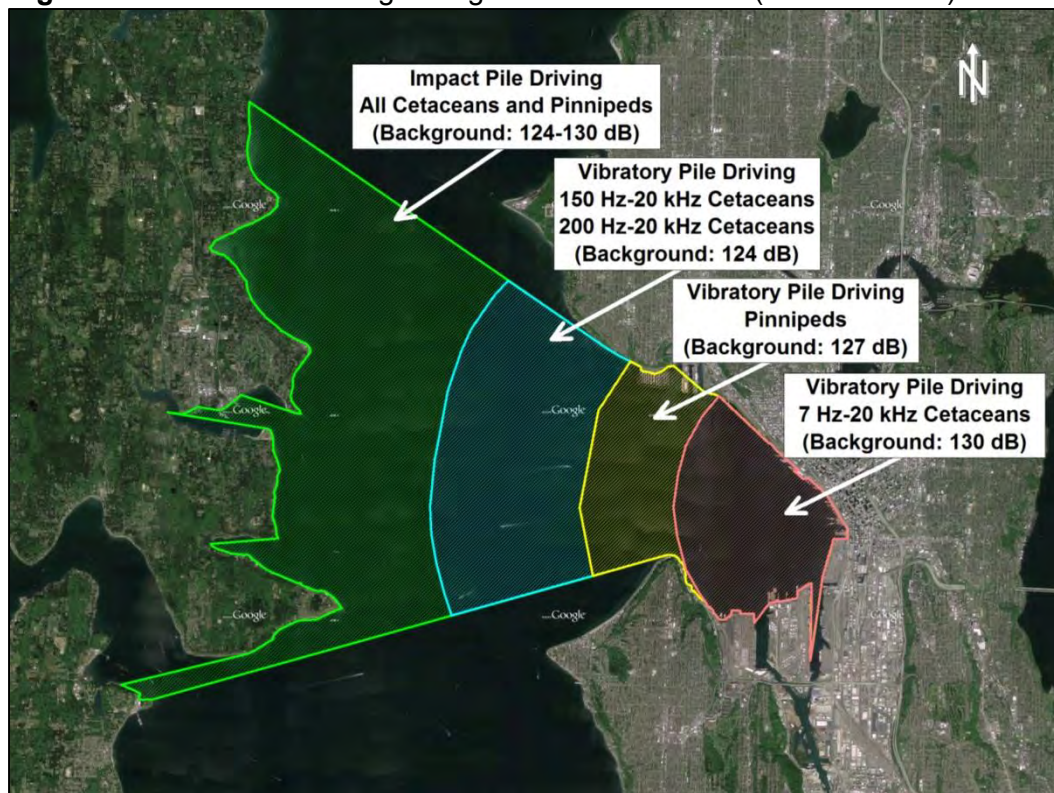
**Table 10.3** Distance to Background Sound Levels Reported by WSDOT 2011

Functional Hearing Group	Frequency Range	RMS, Highest Average (EBSP Season 2)	WSDOT Background Sound Level	Distance to Background
<i>Vibratory Pile Driving</i>				
Cetaceans	7 Hz-20 kHz	168	130	<b>2.1 miles</b>
	150 Hz-20 kHz	168	124	<b>5.4 miles</b>
	200 Hz-20 kHz	168	124	<b>5.4 miles</b>
Pinnipeds	75 Hz-20 kHz	168	127	<b>3.4 miles</b>
<i>Impact Pile Driving</i>				
Cetaceans	7 Hz-20 kHz	185	130	<b>29.0 miles</b>
	150 Hz-20 kHz	185	124	<b>72.9 miles</b>
	200 Hz-20 kHz	185	124	<b>72.9 miles</b>
Pinnipeds	75 Hz-20 kHz	185	127	<b>46.0 miles</b>

Source: The Greenbusch Group, Inc.

As shown in Table 10.3 it is estimated that it will take up to 72.9 miles for underwater sound generated by the impact installation of steel sheet piles to attenuate to the background sound levels measured by WSDOT. However, this distance is reduced due to the proximity of adjacent land masses. Figure 10.2 presents areas where underwater sound levels created by vibratory and impact pile driving of steel sheet piles exceed the background sound levels measured by WSDOT.

**Figure 10.2** Areas Exceeding Background Sound Levels (WSDOT 2011)



Source: The Greenbusch Group, Inc.

### **10.3 Marine Mammal Monitoring**

Monitors observed California sea lions, harbor seals, one Steller sea lion and one humpback whale within the monitoring zone; however these animals did not exhibit any changes in behavior. Details of marine mammal monitoring are presented in a separate report entitled “Marine Mammal Monitoring Season 2 Annual Report, May 15, 2015.”



## 11.0 REFERENCES


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## 12.0 APPENDIX

**Figure 12.1** Vibratory Hammer Information




**Figure 12.2** Impact Hammer Information



## APE Model 6-2 Hydraulic Impact Hammer



**The Worlds Largest Provider of Foundation Construction Equipment**



Specifications	Standard	Metric
Ram Weight	12,000 lbs	5,443.11 kg
Rated Energy	24,000 ft-lbs	32.54 kNm
Stroke at Rated Energy	24 in	60.96 cm
Blows per Minute	45-75 min-max	
Weight without Insert	18,230 lbs	8,268.99 kg
Height	105 in	266.7 cm
Standard Lead Size	8"x26"	

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Specifications may vary due to site conditions, specific hammer conditions or product set up. Specifications may change without notice. Consult the factory for details on any specific product (800) 248-8498.